Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-80

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

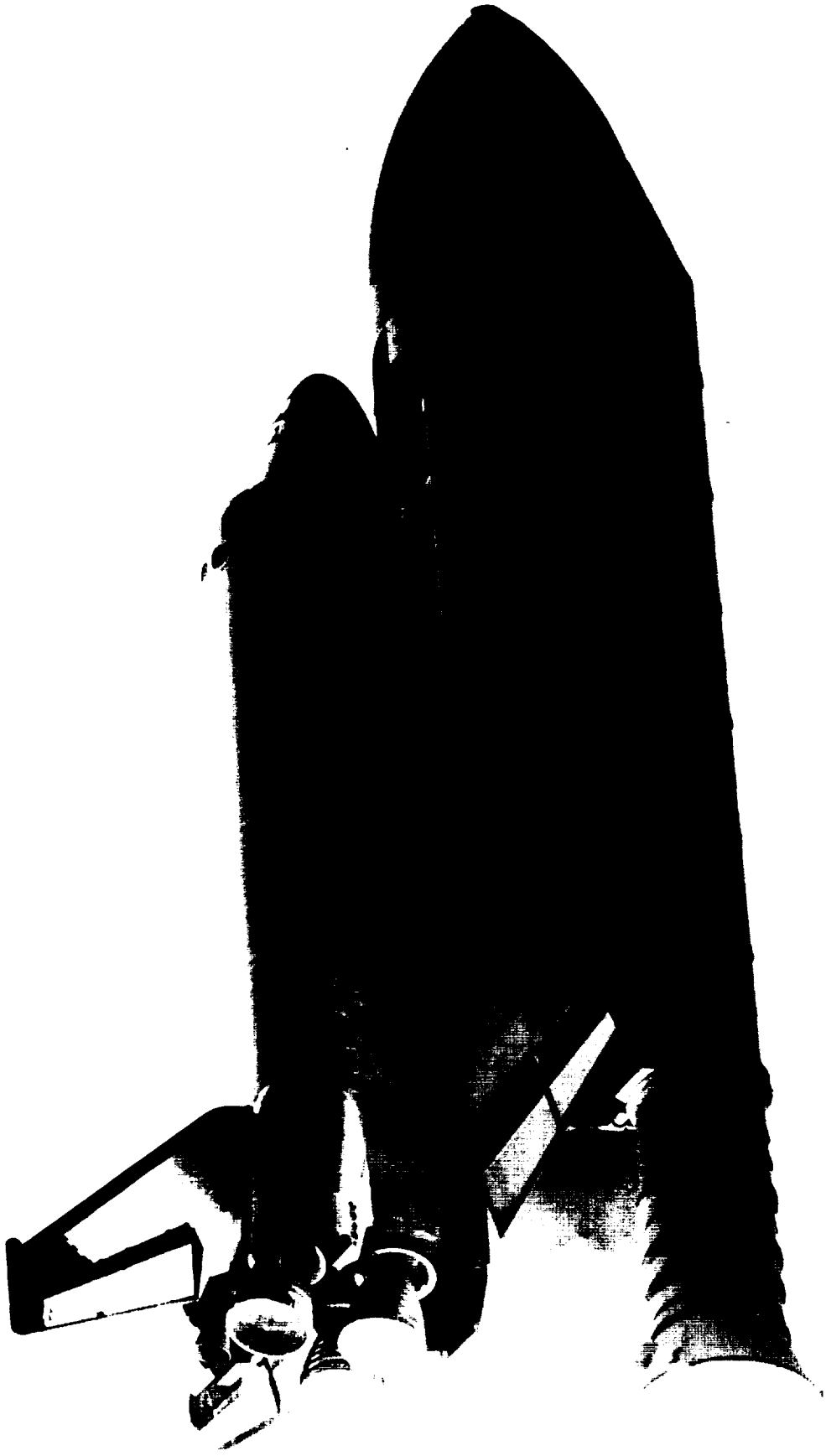


Photo 1 : Launch of Shuttle Mission STS-80

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 November 1996. The detailed walkdown of Pad 39B and MLP-3 also included the primary flight elements OV-102 Columbia (21st flight), ET-80 (LWT 73), and BI-084 SRB's. There were no significant vehicle or pad anomalies.

The vehicle was cryoloaded for flight on 19 November 1996. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. No acreage icing or frost conditions were expected due to the ambient conditions. There were no ice/frost conditions or protuberance icing conditions outside of the established data base.

After the 2:55 p.m. (local) launch on 19 November 1996, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 107 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission.

A stud hang-up occurred on holddown post #7. Two semi-circular objects, believed to be shaved pieces of aluminum from the aft skirt bore, fell aft into the SRB exhaust hole. A piece of ordnance debris, approximately one inch long, fell from the HDP #6 stud hole shortly after lift-off. No ordnance fragments or frangible nut pieces fell from any of the other DCS while in the field of view. No stud hang-ups or frangible nut/ordnance debris was observed on any of the other holddown posts.

SRB separation from the External Tank and ET-80 separation from the Orbiter appeared normal. Four TPS divots were detected on intertank stringers: one forward of the -Y bipod ramp approximately 10-inches long and possibly showing primer; two between the bipods just forward of the splice closeout approximately 4-inches in length with one possibly showing a small area of primer; and one forward of the LO2 feedline fairing near XT-930 approximately 15-inches long and showing stringer head primed substrate. A divot approximately 6-inches in diameter was visible in the LH2 tank-to-intertank flange closeout in the -Y+Z quadrant. The ET/SRB upper strut fairing splice plate closeouts using PDL-1034 foam (third flight) were intact but exhibited small "popcorn" type divots. Aft dome NCFI 24-57 exhibited charring and "popcorn" divoting similar to the previous flight. ET-80 was the second external tank flown that utilized the 141B blowing agent in NCFI formulation.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums were in excellent condition. No MSA-2 debonds over acreage or fasteners were detected.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing inspection of OV-102 was conducted 7 December 1996 on SLF runway 33 at the Kennedy Space Center. The Orbiter TPS sustained a total of 93 hits, of which 8 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger was less than average.

The Orbiter lower surface sustained a total of 34 hits, of which 4 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located aft of the LH2 ET/ORB umbilical and measured 3-inches long by 3/4-inch wide by 1/2-inch maximum depth. The damage was most likely caused by an ice impact from the umbilical.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly.

Bent metal, approximately 1-inch in length by 1/8-inch wide, was visible on the trailing edge of a shim between two bolt heads on the inside surface of the LO2 ET door. The shim was located at the +X+Y corner of the door. A small piece of wire, 3/8-inch long by 1/32-inch diameter, was wedged against a bolt head in this same general area. No reason for the damage or loose debris could be immediately determined. It should be noted no similar shim is located on the LH2 ET door (mirror image).

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 18 November 1996 at 1400 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC Shuttle Ice/Debris Systems
J. Lin	NASA - KSC Shuttle Ice/Debris Systems
R. Speece	NASA - KSC Thermal Protection Systems
B. Bowen	NASA - KSC Infrared Scanning Systems
J. Rivera	NASA - KSC ET Mechanisms/Structures
M. Bassignani	NASA - KSC ET Mechanisms/Structures
B. Davis	NASA - KSC Digital Imaging Systems
Z. Byrns	NASA - KSC Level II Integration
M. Valdivia	USA - SPC Supervisor, ET/SRB Mechanical Systems
R. Seale	USA - SPC ET Mechanical Systems
J. Blue	USA - SPC ET Mechanical Systems
W. Richards	USA - SPC ET Mechanical Systems
M. Wollam	USA - SPC ET Mechanical Systems
G. Fales	USA - SPC ET Mechanical Systems
K. Mayer	Rockwell LSS Systems Integration
W. Atkinson	Rockwell LSS Systems Integration
J. Cook	THIO - LSS SRM Processing
J. Ramirez	LMSO - LSS ET Processing

3.0 LAUNCH

STS-80 was launched at 96:324:19:55:46.990 UTC (2:55 p.m. local) on 19 November 1996.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 November 1996. The detailed walkdown of Pad 39B and MLP-3 also included the primary flight elements OV-102 Columbia (21st flight), ET-80 (LWT 73), and BI-084 SRB's. There were no significant vehicle or launch pad anomalies.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 19 November 1996 from 1020 to 1150 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. No acreage icing or frost conditions were expected due to the afternoon launch time and favorable weather conditions. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R1U, R4D, L4D, and F4R RCS thruster covers were intact, but tinted green indicating small internal vapor leaks. Ice/frost and condensate had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. Condensate was present on the SSME #3 heat shield-to-nozzle interface. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers averaged 68-72 degrees F. Temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 68-75 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 71 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank. TPS surface temperatures ranged from 61-64 degrees F. A bungee cord from the southwest GOX vent seal, contacting the nose cone TPS early in the cryoload, left a 1-inch long by ¼-inch wide discoloration, but no apparent abrasion.

The intertank acreage exhibited no TPS anomalies. Ice/frost accumulation on the GUCP appeared typical even with the leak detected during cryoload.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank. TPS surface temperatures ranged from 53-63 degrees F.

Photo 2: STS-80 Cryoloaded for Launch

OV-102 Columbia (21st flight), ET-80 (LWT 73), and BI-084 SRB's

Photo 3: Overall View of SSME's

Photo 4: ET LO2 Tank and Intertank

Very light condensate, but no ice or frost accumulations, was observed on the LO2 tank. TPS surface temperatures ranged from 61-64 degrees F. The intertank acreage exhibited no TPS anomalies.

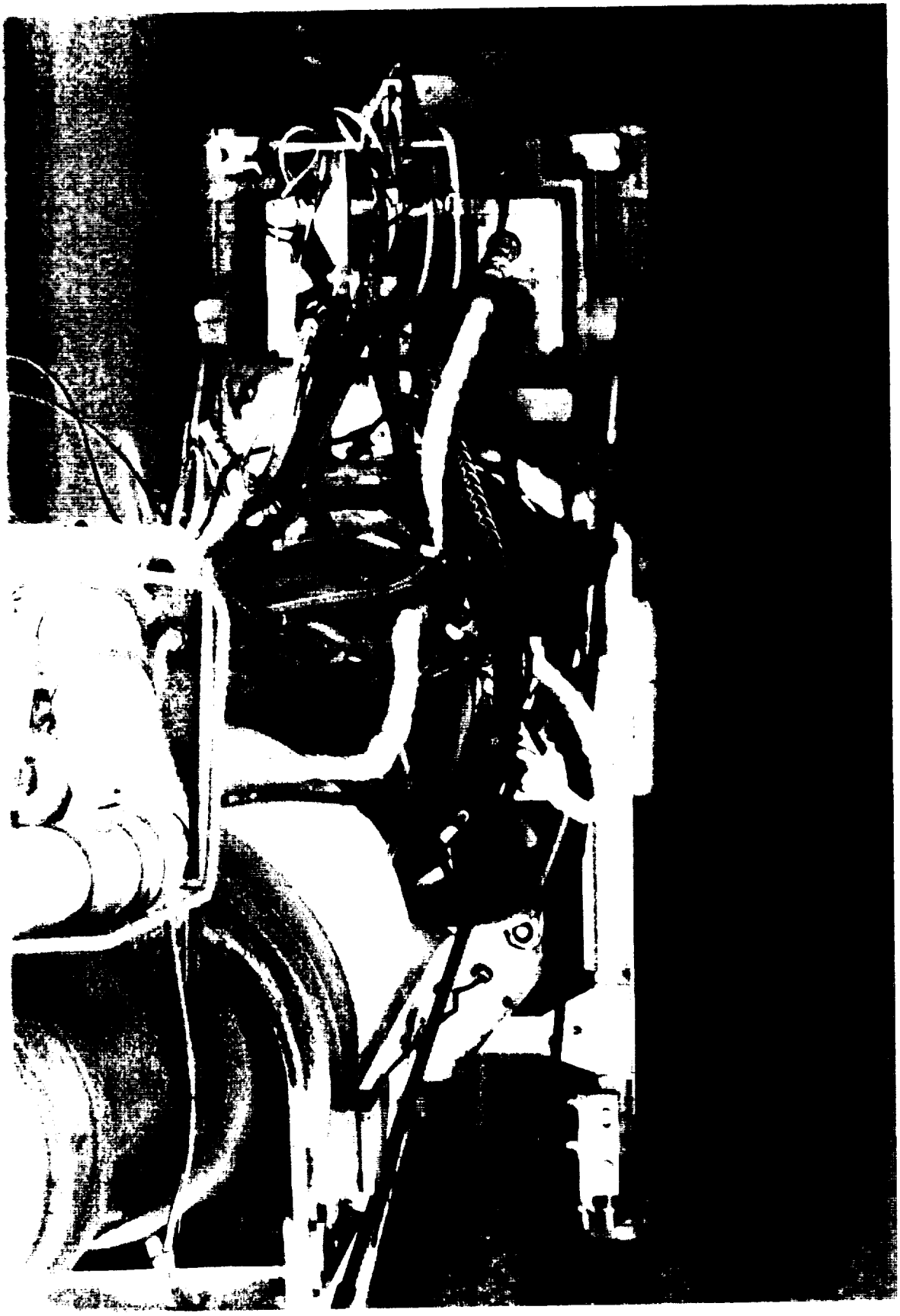


Photo 5: GUCP

Ice/frost accumulation on the GUCP appeared typical even with the leak detected during cryoload.

Photo 6: ET LH2 Tank

Very light condensate, but no ice or frost accumulations, was observed on the LH2 tank. TPS surface temperatures ranged from 53-63 degrees F.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

An 11-inch long by ¼-inch wide stress relief crack had formed on the -Y vertical strut forward facing TPS. The presence of the crack was expected and acceptable for flight per the NSTS-08303 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch.

During launch countdown, a leak was reported in the GUCP. Postflight analysis of the GUCP showed that the leak was caused by low compression loads in the 7-inch quick disconnect bellows. There were no visible signs of leaks, unusual vapors, or ice buildup detected during the final inspection.

No leaks were observed on the LO2 and LH2 Orbiter T-0 umbilicals.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS, RSS, and Pad B crawlerway/acreage was conducted on 19 November 1996 for 1.5 hours starting at Launch + 1.5 hours.

No flight hardware or TPS materials were found.

South SRB holddown post and shoe erosion was typical. All south HDP shoe shim material was intact. No externally visible evidence of a HDP stud hang-up was found. But based on vehicle liftoff lateral acceleration of 0.26g's reported by Rockwell-Downey, a stud hand-up did likely occur. A stud hang-up on HDP #7 was later confirmed during post-launch film review. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was typical.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA) and GOX Vent Arm (GVA) had no visible indications of damage. Both TSM bonnets closed properly.

The GH2 vent line was latched in the seventh of eight teeth of the latching mechanism. The ET GUCP had been struck by the retract lanyard as indicated by bright raised metal on the housing. Damage to the GUCP was minimal. The raised metal was in the peripheral seal gap at the bottom of the GUCP housing. The sealing surface of the 7-inch GH2 Vent Q/D was not damaged. There was no indication of the source of the GH2 leak reported during the launch countdown.

A piece of SRB throat plug, with RTV attached, measuring 6 inches by 12 inches by 12 inches was found on the roadway to the pad surface.

Two broken ceramic insulators from an OTV camera cable was found on the southeast corner of the FSS 195 foot level

Overall, damage to the pad appeared to be minimal.

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 83 films and videos, which included twenty-seven 16mm films, eighteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

A cold wall leak occurred on SSME #2 (-Z side near the #9 hatband) after the Mach diamond had formed 19:55:44.5 UTC (E-1, -5, -16). Otherwise, SSME ignition appeared normal (OTV 151, 163, 170, 171, TV-4; E-76).

Pieces of tile surface coating material were lost from two places on the base heat shield outboard of SSME #3, four places on the base heat shield between SSME #1 and #3, and two places on the right APCS pod aft surface (E-17, -19).

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice contacted the LH2 umbilical cavity sill and were deflected outward. No tile damage was visible. No unusual vapors or cryogenic drips were visible.(OTV 109, 141, 154, 163).

A debris-induced streak occurred in the SSME #2 plume at 19:55:46.6 UTC (E-20).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150, 170, 171). A 3-inch long by 1-inch wide rectangular object, possibly an umbilical shim, fell aft during LH2 T-0 disconnect. The object did not contact flight hardware (E-18).

GUCP disconnect from the ET was nominal (OTV 141, 160). A typical amount of frost, but no TPS damage, was visible around the lower half of the ET umbilical carrier plate (E-33).

A stud hang-up occurred on holddown post #7. The stud remained fully extended until the aft skirt cleared, then twanged briefly before falling into the holddown post. Two semi-circular objects, believed to be shaved pieces of aluminum from the aft skirt bore, appeared to fall aft into the SRB exhaust hole. No ordnance fragments or frangible nut pieces fell from the DCS while in the field of view (E-11). Analysis of film item E-11 showed the stud rising 8.3 inches above the holddown post shoe before falling back into the holddown post (Figure 1).

No stud hang-ups or frangible nut/ordnance debris was observed on any of the other holddown posts with the exception of HDP #6. An ordnance fragment, approximately 1-inch long, fell from the stud hole shortly after liftoff (E-13).

A piece of holddown post shoe shim or putty may have adhered to the right aft skirt #2 foot momentarily at T-0 before falling back onto the shoe (E-8).

A piece of thermal curtain tape (near HDP #7) came loose at liftoff (E-16).

Outgassing and charring of ET aft dome NCFI was occurring as the vehicle cleared the tower (E-40, -52, -224).

At least 11 small, light-colored particles, believed to be pieces of instafoam, originated from the RH SRB aft skirt area shortly after the roll maneuver and fell aft along the SRB plume (E-57).

Body flap movement (amplitude and frequency) was clearly visible in film item E-212.

Photo 7: Base Heat Shield Tile Damage

Pieces of tile surface coating material were lost from four places on the base heat shield between SSME #1 and #3..

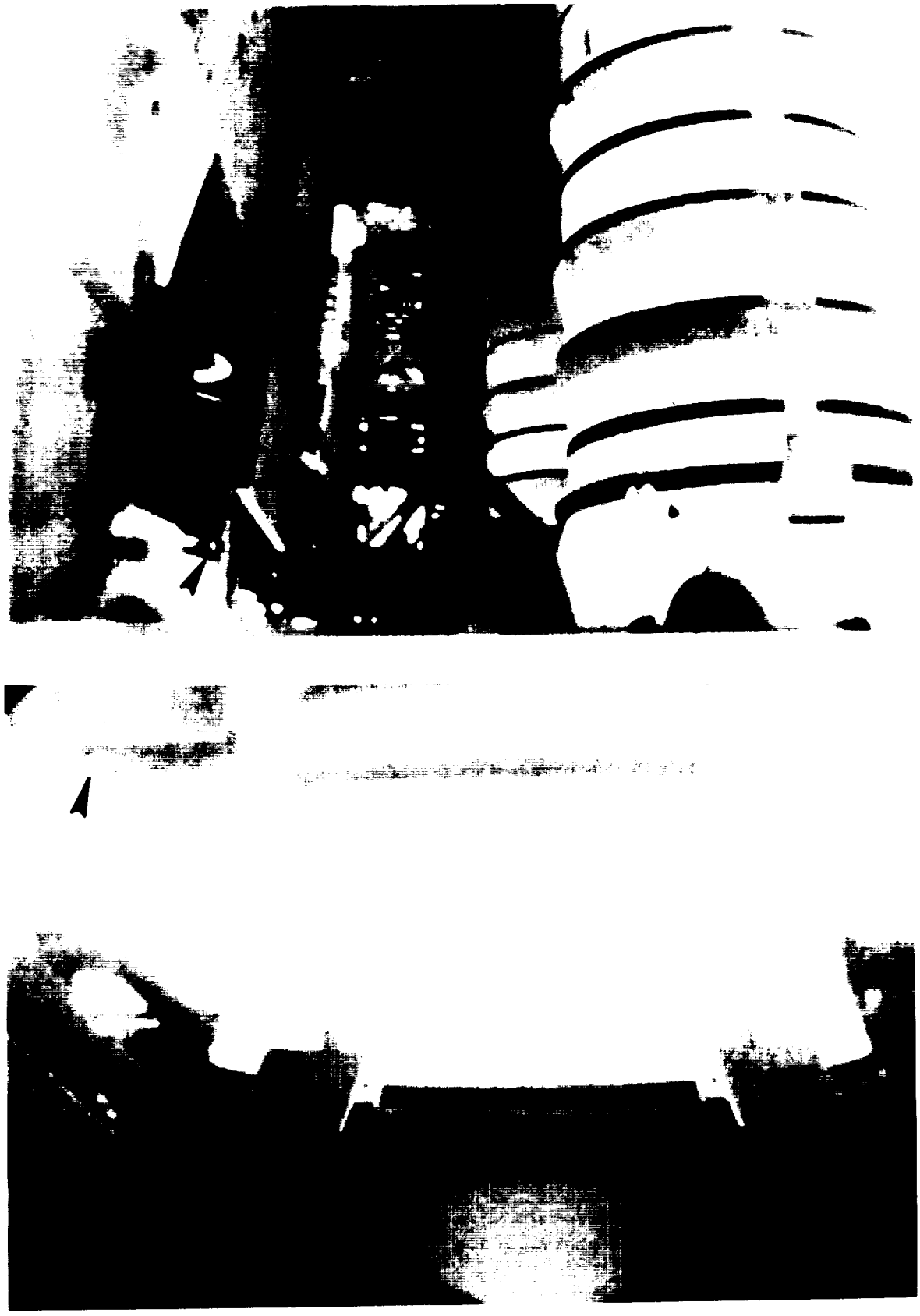


Photo 8: SSME #2 Cold Wall Leak

A cold wall leak occurred on SSME #2 (-Z side near the #9 hatband) after the Mach diamond had formed

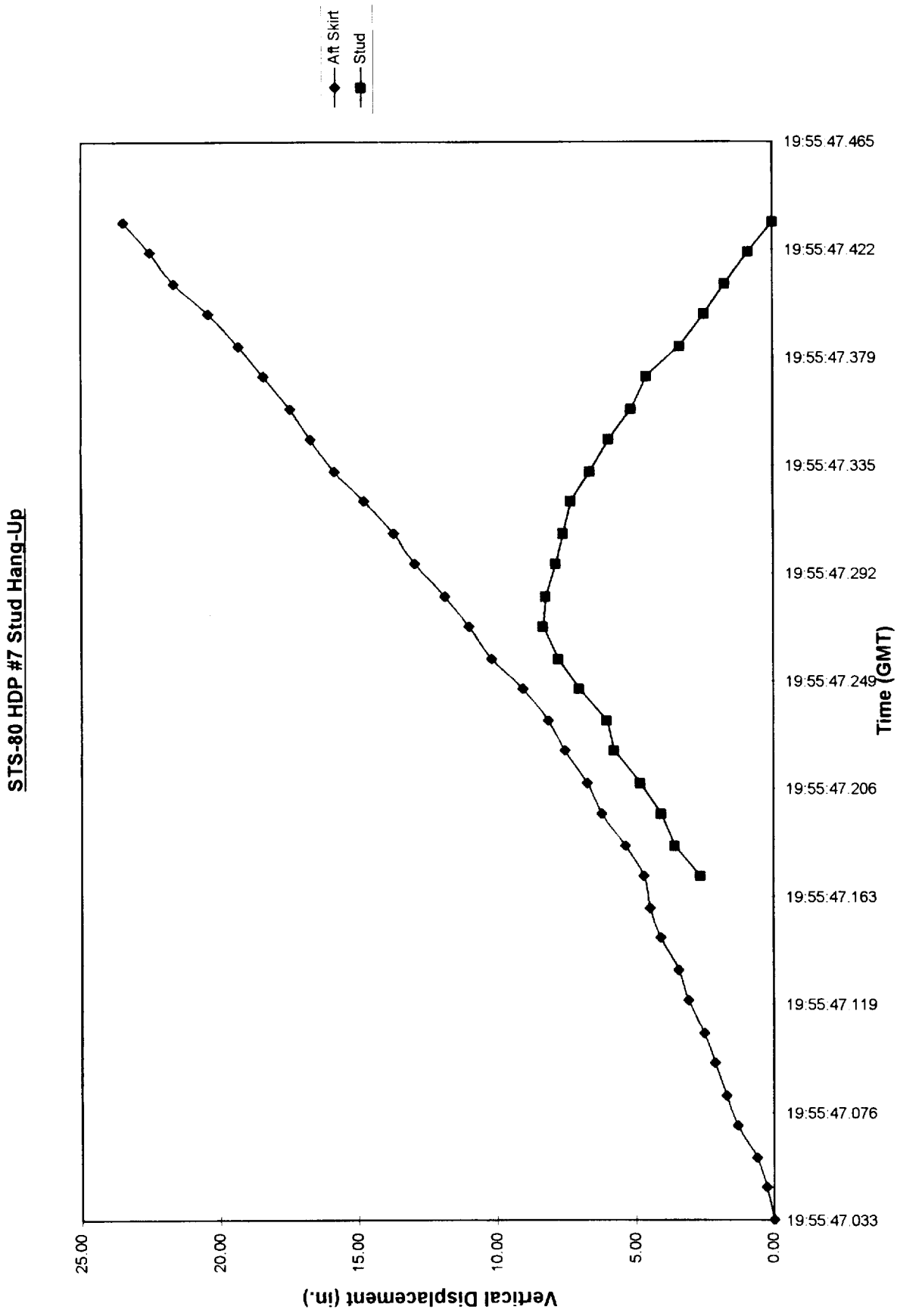


Figure 1: Holddown Post #7 Stud Hang-Up

Photo 9: Holddown Post #7 Stud Hang-Up

A stud hang-up occurred on holddown post #7. The stud remained fully extended until the aft skirt cleared, then twanged briefly before falling into the holddown post. Two semi-circular objects, believed to be shaved pieces of aluminum from the aft skirt bore, appeared to fall aft into the SRB exhaust hole.

Local flow condensation collars at various points on the vehicle were observed during ascent (E-223).

Exhaust plume recirculation, though more visible on this launch due to a variety of factors including lighting conditions, vehicle attitude, and camera positions, did not appear anomalous (TV-4, 13; E-205, -208).

SRB separation appeared normal. Slag fell from the exhaust plumes during and after separation (TV-13; E-205, -208, -212).

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-102 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The +X translation was not performed on this flight. Handheld photography by the flight crew consisted of nine still 35mm images.

SRB separation from the External Tank appeared nominal.

ET-80 separation from the Orbiter also appeared normal.

Four TPS divots were detected on intertank stringers: one forward of the -Y bipod ramp approximately 10-inches long and possibly showing primer; two between the bipods just forward of the splice closeout approximately 4-inches in length with one possibly showing a small area of primer; and one forward of the LO2 feedline fairing near XT-930 approximately 15-inches long and showing stringer head primed substrate.

The new method bipod jack pad standoff closeouts were intact and undamaged. A divot approximately 6-inches in diameter was visible in the LH2 tank-to-intertank flange closeout in the -Y+Z quadrant.

TPS erosion on LO2 feedline flanges and support bracket ramps, pressurization line ramps, and both thrust strut flange closeouts was typical.

Four shallow divots 2-3 inches in diameter were observed on the +Y vertical strut outboard surface.

The ET/SRB upper strut fairing splice plate closeouts using PDL-1034 foam (third flight) were intact but exhibited small "popcorn" type divots.

A dark, relatively smooth, circular area approximately 5-inches in diameter on the -Y vertical strut aft surface appeared different than the adjacent charred and rough-textured BX-250. Shadow lengths indicate this circular feature is probably no greater than 0.5-inches deep and most likely did not expose the underlying ablator.

The LH2 ET/ORB umbilical appeared to be in good condition after separation with no TPS damage. Frozen hydrogen adhered to the 17-inch disconnect and parts of the separation interface. Typically, foam had eroded from the horizontal (clamshell) section of the cable tray and the LH2 feedline support arm.

The LO2 ET/ORB umbilical sustained TPS damage during separation at the forward outboard corner. Two pieces of loose foam were visible in that area. Part of the RTV purge barrier was detached at the 2:00 o'clock position. Minor TPS damage also occurred on the umbilical aft surface near the electrical monoball. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. Lightning contact strips across the forward part of the umbilical and at the 8:00 o'clock position were missing. Loss of lightning contact strips has been the subject of previous IFA's.

Aft dome NCFI 24-57 exhibited charring and "popcorn" divoting similar to the previous flight (second flight with usage of the 141B blowing agent in NCFI formulation).

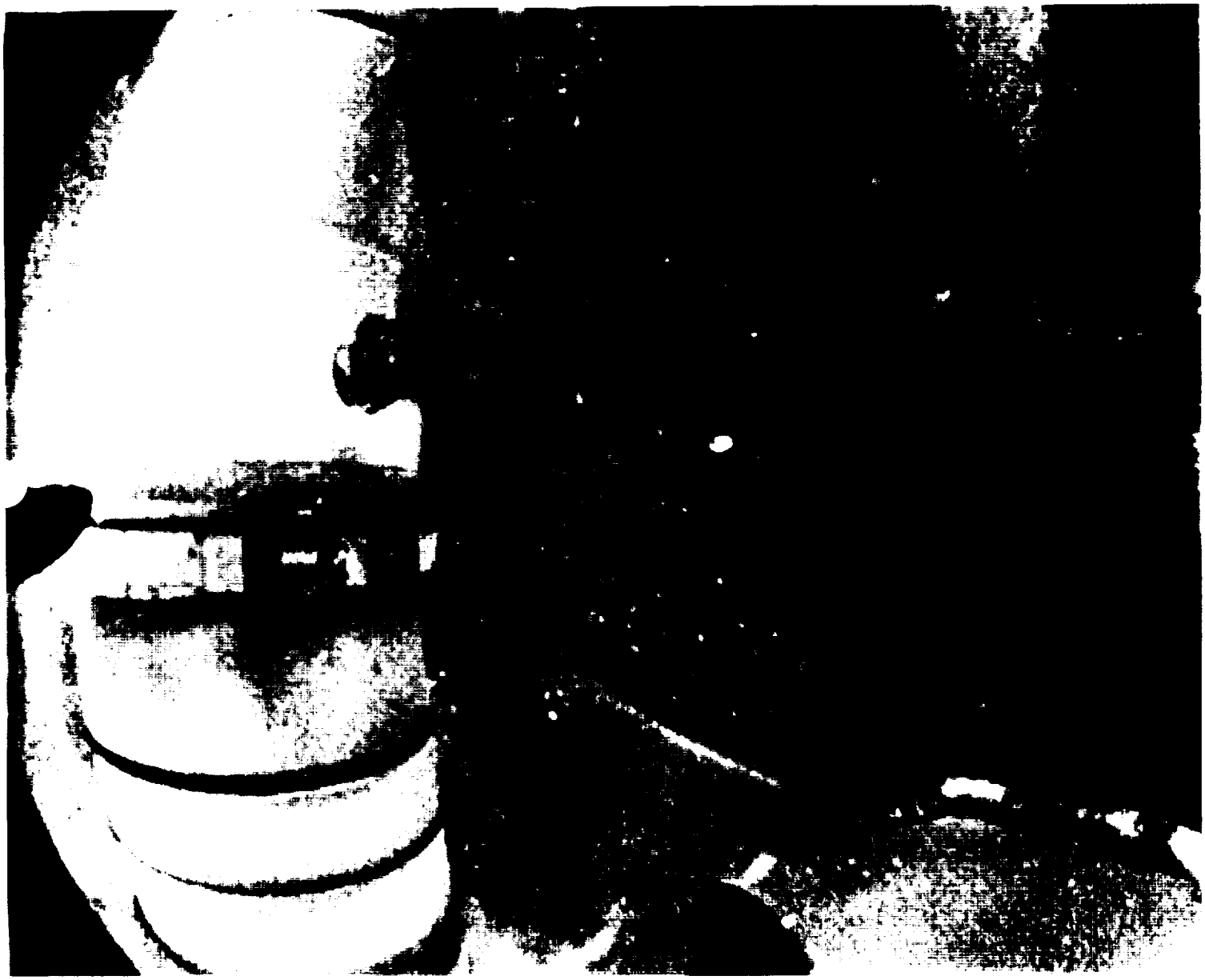


Photo 10: SRB Separation

SRB separation from the External Tank appeared nominal

Photo 11: ET Intertank TPS Divots

Four TPS divots were detected on intertank stringers: one forward of the -Y bipod ramp approximately 10-inches long and possibly showing primer; two between the bipods just forward of the splice closeout approximately 4-inches in length with one possibly showing a small area of primer; and one forward of the LO2 feedline fairing near XT-930 approximately 15-inches long and showing stringer head primed substrate.

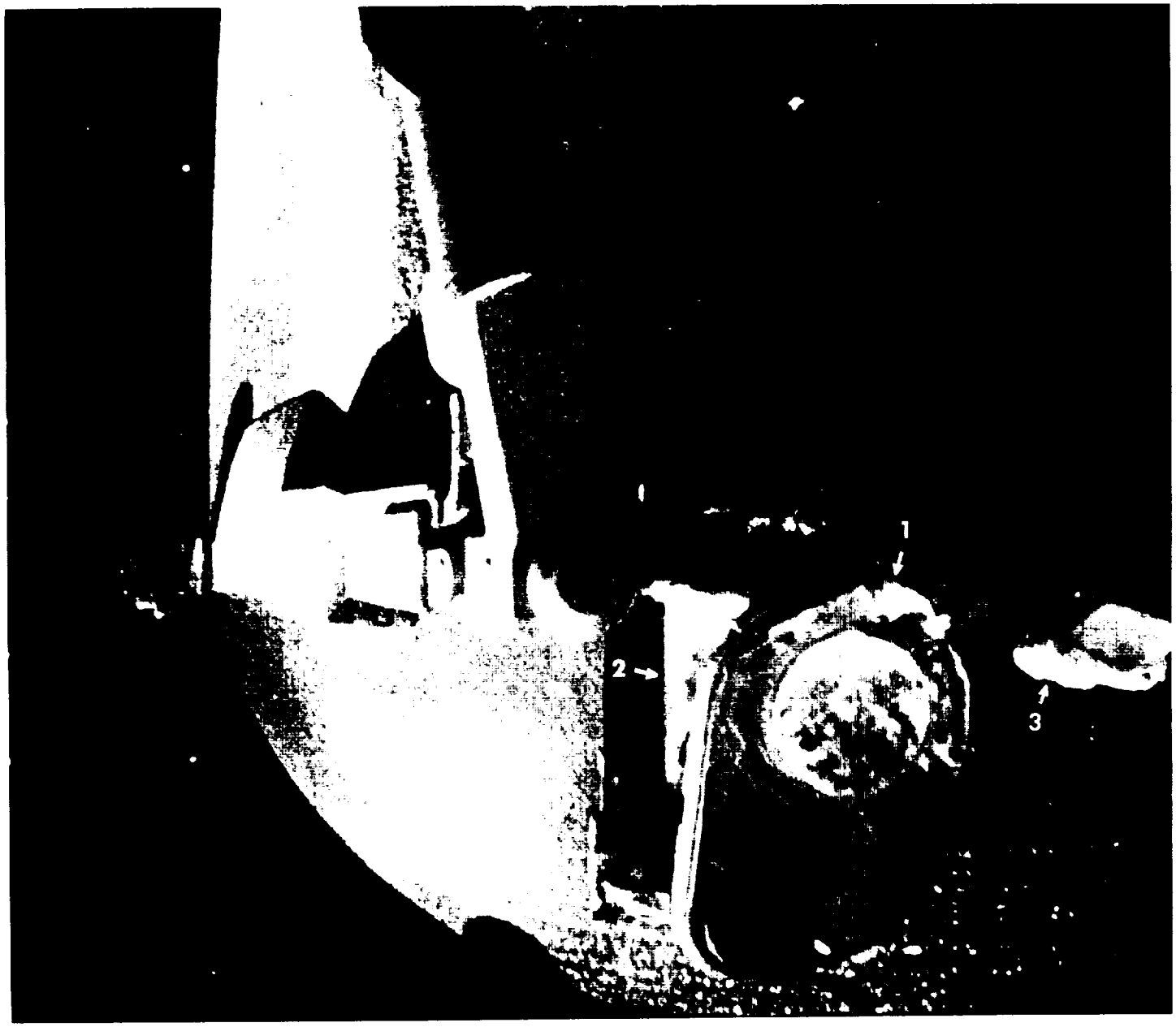


Photo 12: ET/ORB LH2 Umbilical

The LH2 ET/ORB umbilical appeared to be in good condition after separation with no TPS damage. Frozen hydrogen adhered to the 17-inch disconnect and parts of the separation interface (1). Typically, foam had eroded from the horizontal (clamshell) section of the cable tray and the LH2 feedline support arm (2). A piece of foam, most likely from the LO2 umbilical forward face, was visible near the LH2 umbilical (3).

Photo 13: ET/ORB LO2 Umbilical

The LO2 ET/ORB umbilical sustained TPS damage during separation at the forward outboard corner. Two pieces of loose foam were visible in that area (1). Part of the RTV purge barrier was detached at the 2:00 o'clock position (2). Minor TPS damage also occurred on the umbilical aft surface near the electrical monoball (3). Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray (4). Lightning contact strips across the forward part of the umbilical (5) and at the 8:00 o'clock position were missing (6). Four shallow divots 2-3 inches in diameter were observed on the +Y vertical strut outboard surface (7).

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 21 films and videos, which included nine 35mm large format films, two 16mm high speed films, and ten videos, were reviewed. The films were generally dark due to the pre-dawn lighting conditions.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. Left and right main landing gear touchdown was virtually simultaneous at approximately 3,000 feet from the runway threshold. The Orbiter stayed close to the runway centerline during rollout.

Drag chute deployment appeared nominal.

Touchdown of the nose landing gear was smooth. Rollout and wheel stop were uneventful.

No significant TPS damage was visible in the films.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-084 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 21-22 November 1996. From a debris standpoint, both SRB's were in excellent condition.

Both frustums were in excellent condition. No TPS was missing. No MSA-2 debonds over acreage or fasteners were detected. Hypalon paint, usually blistered/missing along the XB-395 ring frames, was intact and virtually unscorched. The only blistered Hypalon paint was located on the left frustum in a band between the XB-318 and XB-336 ring frames from the -Z to the +Z axes; and between the XB-352 and XB-367 ring frames generally aft of the BSM's. All eight BSM aero heat shield covers were undamaged and locked in the fully opened position.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact though some of the phenolic layers had delaminated. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. A pin and retainer clip were missing from the right frustum severance ring at approximately 90 degrees. The pin and clip may have been lost after water impact due to parachute riser entanglement.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. Water impact deformed the right SRB upper strut fairing. Cork insulation was missing from an area approximately 6-inches long by 4-inches wide on the aft side. The exposed, primed substrate was clean and may indicate the insulation had not adhered. The ETA ring, IEA, and IEA covers appeared undamaged from splashdown though the protective foam was debonded or missing in many areas.

TPS on the external surface of both aft skirts was intact and in good condition. Internally, foam was missing and substrate exposed on the right aft skirt aft ring.

A stud hang-up occurred on HDP #7 and the hole was broached. The stud hang-up was confirmed in the launch film review on film item E-11. Stud hang-ups have occurred on 6 of the last 9 launches (STS-72 through STS-80). Prior to this interval, no stud hang-ups occurred for 19 consecutive launches (STS-53 through STS-71).

The HDP #5 and #6 debris plungers were fully extended, but slightly skewed and not completely seated. A piece of ordnance debris, approximately one inch long, fell from the HDP #6 stud hole shortly after liftoff (film item E-13). The remaining HDP Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally.

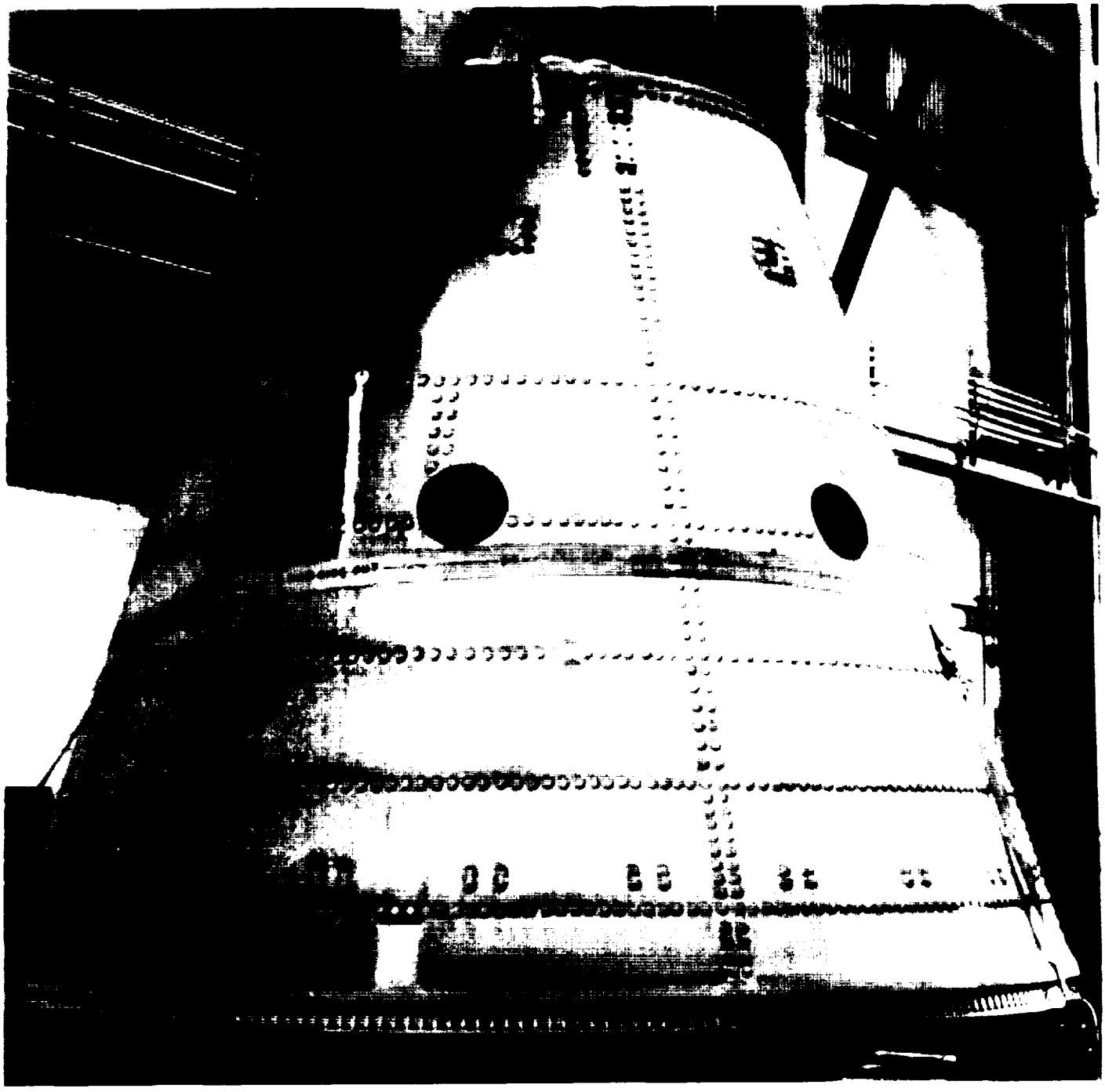


Photo 14: RH Frustum

The righthand frustum was in excellent condition. No TPS was missing. No MSA-2 debonds over acreage or fasteners were detected

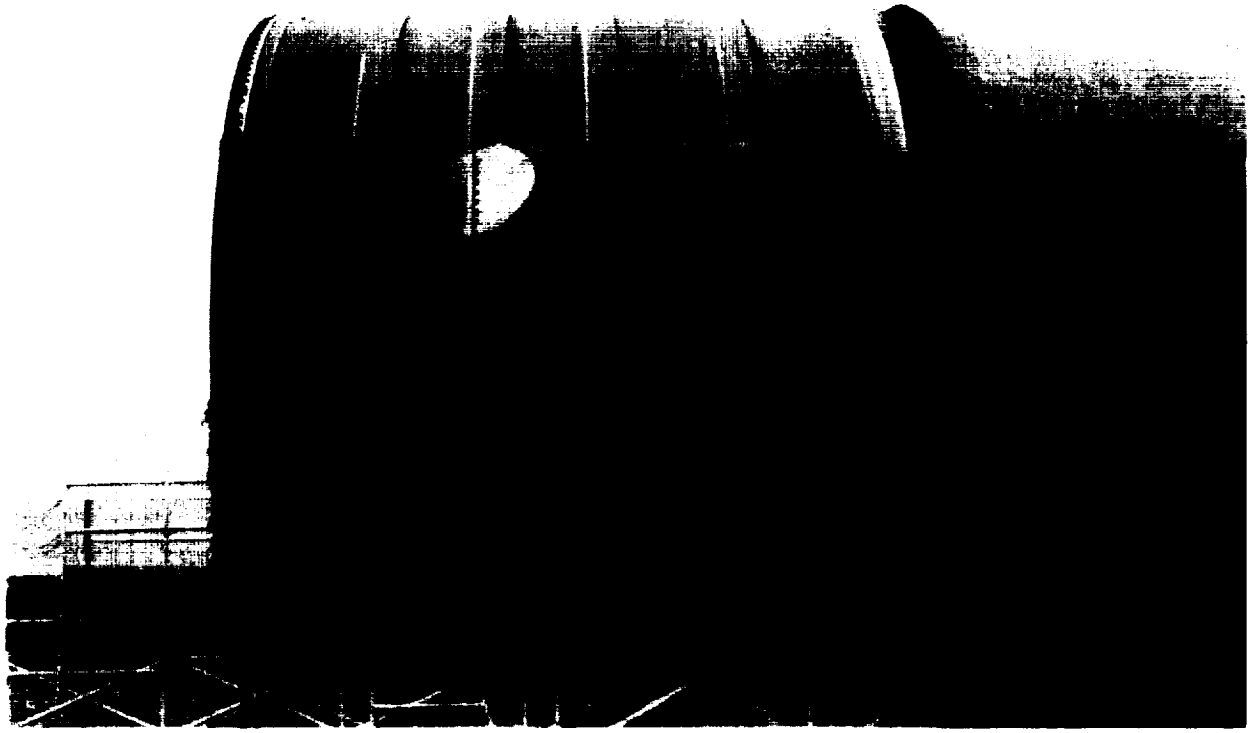


Photo 15: RH Forward Skirt

Photo 16: RH Aft Booster/Aft Skirt

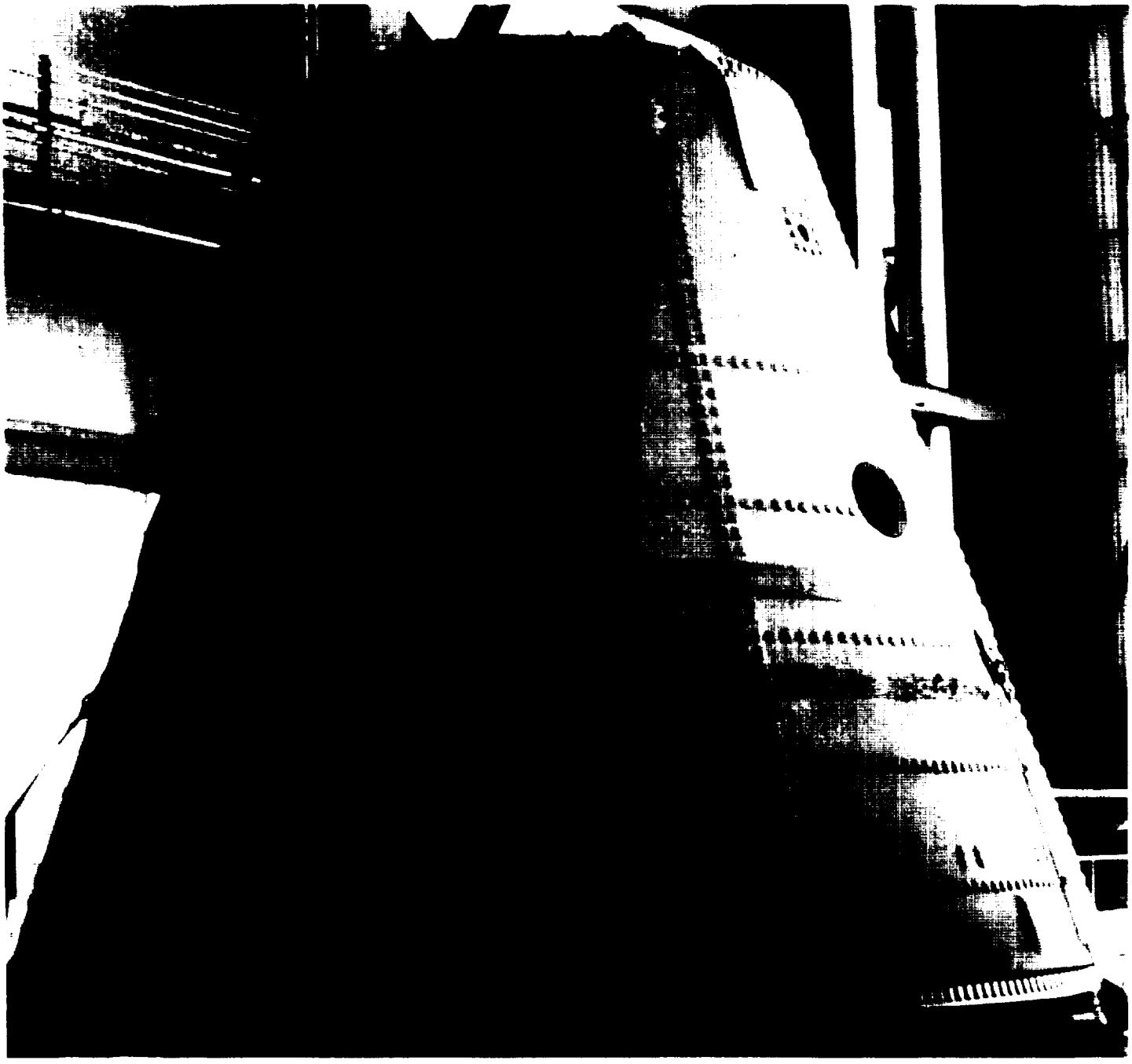


Photo 17: LH Frustum

Hypalon paint was blistered in a band between the XB-318 and XB-336 ring frames from the -Z to the +Z axes; and between the XB-352 and XB-367 ring frames generally aft of the BSM's.

Photo 18: LH Forward Skirt

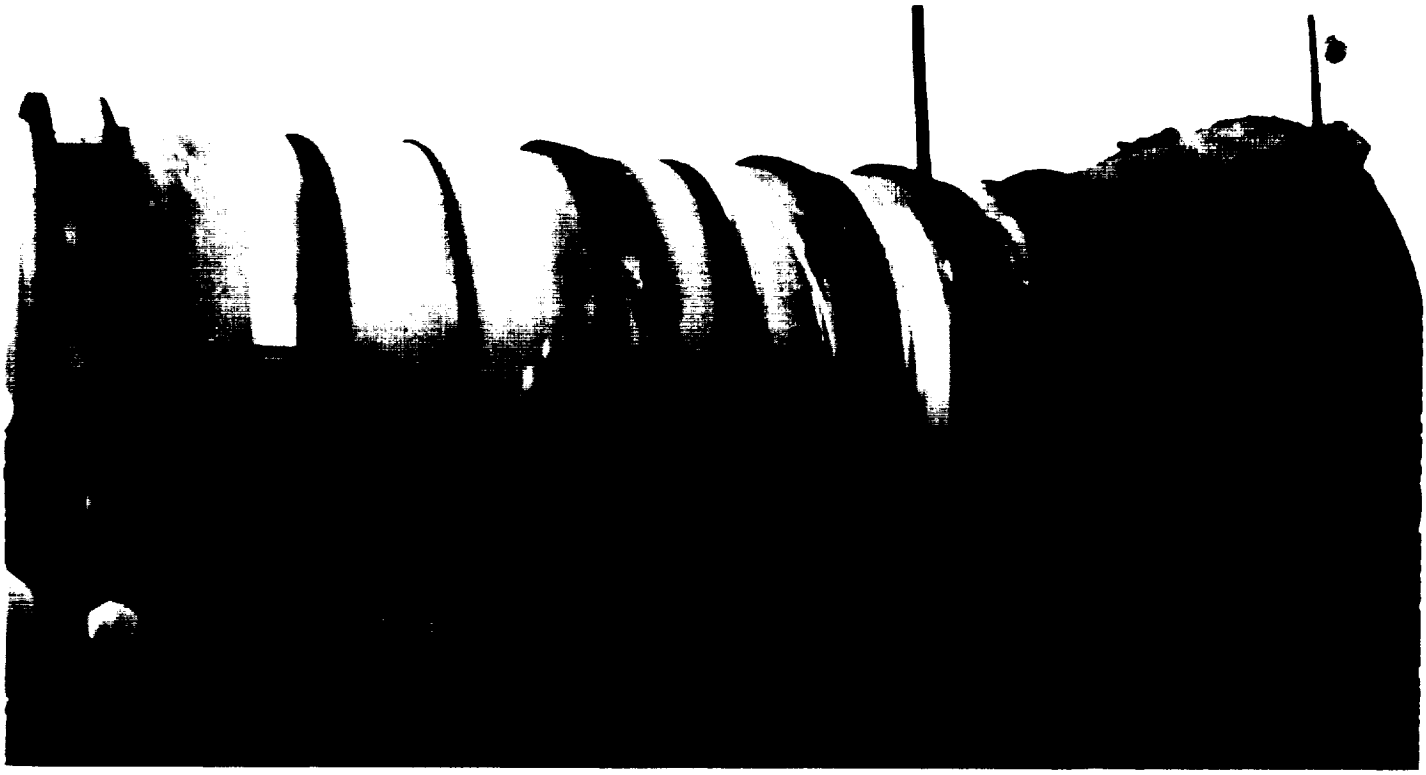


Photo 19: LH Aft Booster/Aft Skirt

Photo 20: HDP #7 Stud Hole Broaching

A stud hang-up occurred on HDP #7 and the hole was broached. The stud hang-up was confirmed in the launch film review on film item E-11.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-102 Columbia was conducted 7-8 December 1996 at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #1. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 93 hits, of which 8 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 64 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger were less than average (Reference attached figures. No debris impacts were noted on both the left and right sides of the Orbiter, so the corresponding figures have been omitted).

The following table breaks down the STS-80 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	4	34
Upper surface	4	54
Right side	0	0
Left side	0	0
Right OMS Pod	0	2
Left OMS Pod	0	3
TOTALS	8	93

The largest lower surface tile damage site was located aft of the LH2 ET/ORB umbilical and measured 3-inches long by 3/4-inch wide by 1/2-inch maximum depth. The damage was most likely caused by an ice impact from the umbilical.

Tile damage sites aft of the LH2 and LO2 ET/ORB umbilicals were otherwise typical in number and size. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

No tile damage from micrometeorites or on-orbit debris was identified during this inspection.

The tires and brakes were reported to be in average condition for a landing on the KSC concrete runway. Ply undercutting occurred on the LH main inboard tire.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. However, loose pieces of white RTV hung from two of the three umbilical pyro separation devices.

Bent metal, approximately 1-inch in length by 1/8-inch wide, was visible on the trailing edge of a shim between two bolt heads on the inside surface of the LO2 ET door. The shim was located at the +X+Y corner of the door. A small piece of wire, 3/8-inch long by 1/32-inch diameter, was wedged against a bolt head in this same general area. No reason for the damage or loose debris could be immediately determined. It should be noted no similar shim is located on the LH2 ET door (mirror image).

All three SSME Dome Mounted Heat Shield (DMHS) closeout blankets sustained some damage. The SSME #1 blanket was torn/frayed at the 5:00-6:00 o'clock position. Some of the batting material may be missing. The SSME #2 blanket was torn/frayed at the 12:00-1:00 and 4:00-5:00 o'clock positions, but no material appeared to be missing. The SSME #3 blanket at the 9:00 o'clock position was slightly frayed at the outboard edge.

A cluster of seven tiles on the base heat shield between SSME #1 and #3 sustained greater than normal damage, which may have been the result of debris impacts rather than plume recirculation effects. The tiles were missing a large percentage of surface area with the average depth measuring ¼-inch.

No ice adhered to the payload bay door. The reddish-brown discoloration on the leading edge of the LH payload bay door had not changed in appearance. No unusual tile damage occurred on the leading edges of the vertical stabilizer and OMS pods.

Hazing and streaking of Orbiter windows #2, #3, #4 and #5 appeared to be less than usual. Damage sites on the window perimeter tiles (10 hits on window #2, 7 hits on #3, 6 hits on #4, and 11 hits on #5) were attributed to impacts from the FRCS thruster paper covers/RTV adhesive.

The post landing walkdown of Runway 33 was performed immediately after landing. No debris concerns were identified. All drag chute hardware was recovered and appeared to have functioned normally.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were less than average when compared to previous missions.

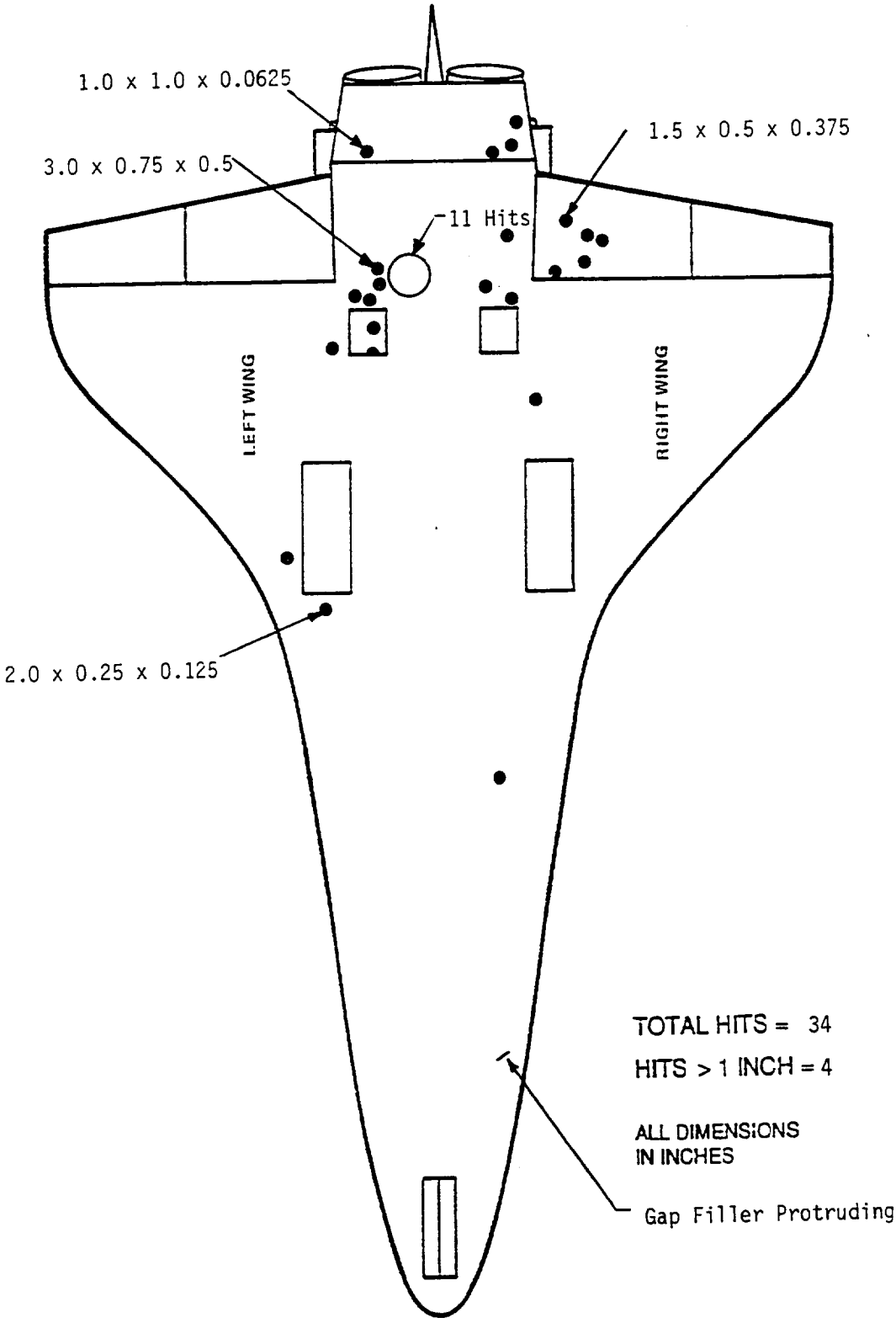


Figure 2: Orbiter Lower Surface Debris Map

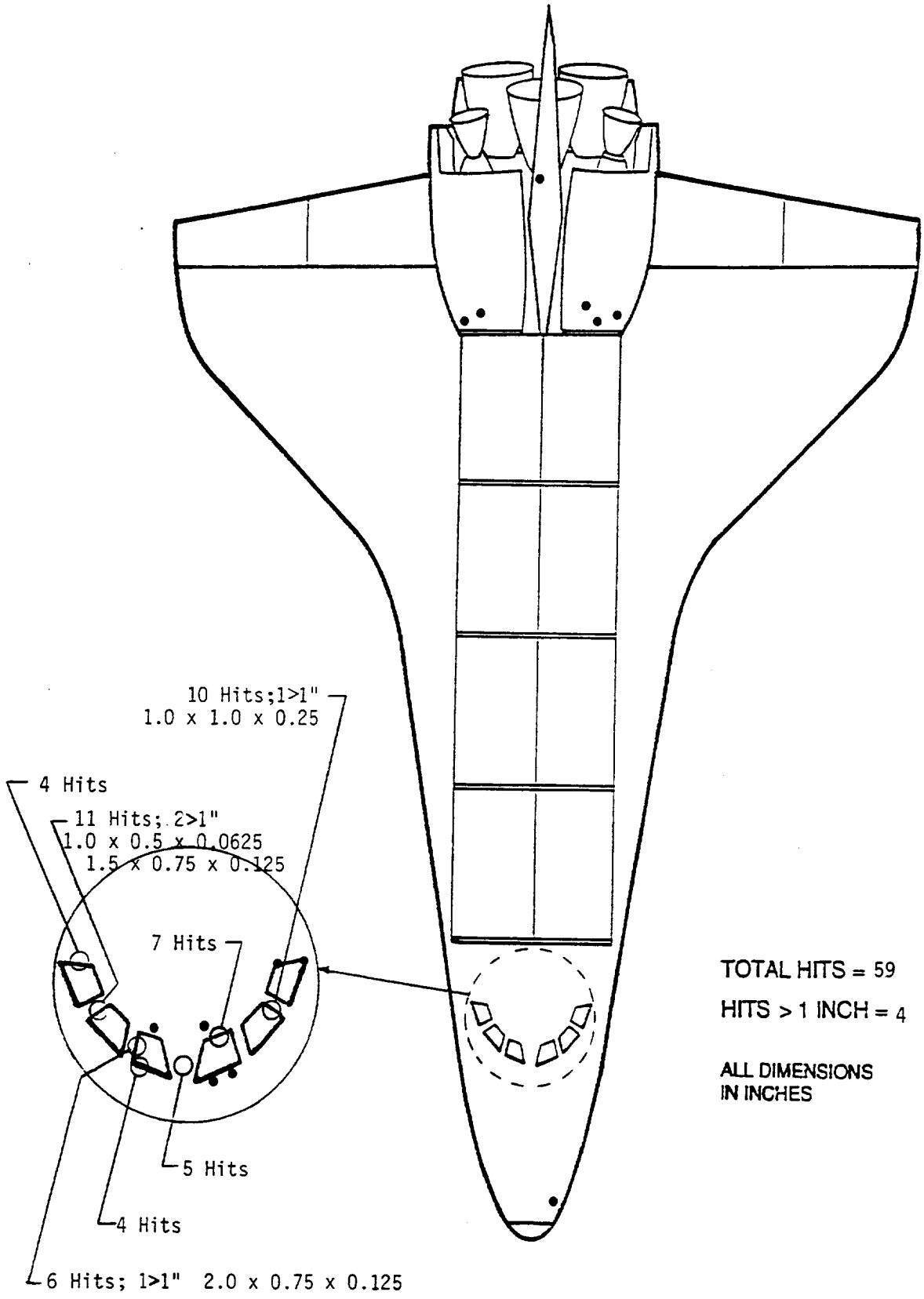


Figure 3: Orbiter Upper Surface Debris Map

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
AVERAGE	13.7	87.5	20.3	127.3
SIGMA	7.3	44.1	9.7	53.7
STS-80	4	34	8	93

MISSIONS STS-23,24,25,26,26R,27R,30R,AND42R ARE NOT INCLUDED IN THIS ANALYSIS SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 4: Orbiter Post Flight Debris Damage Summary

Photo 21: Overall View of Orbiter Left Side

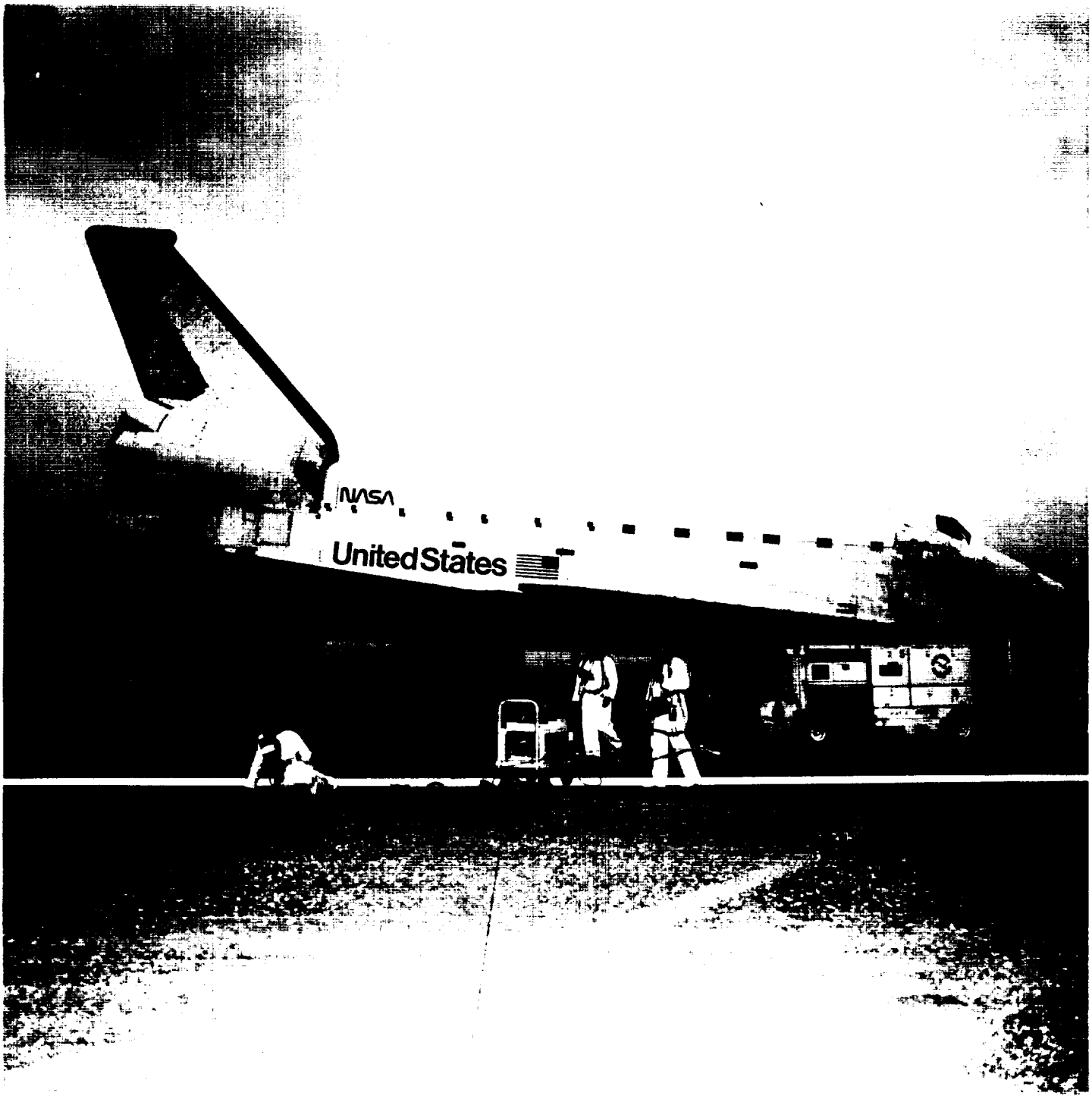


Photo 22: Overall View of Orbiter Right Side

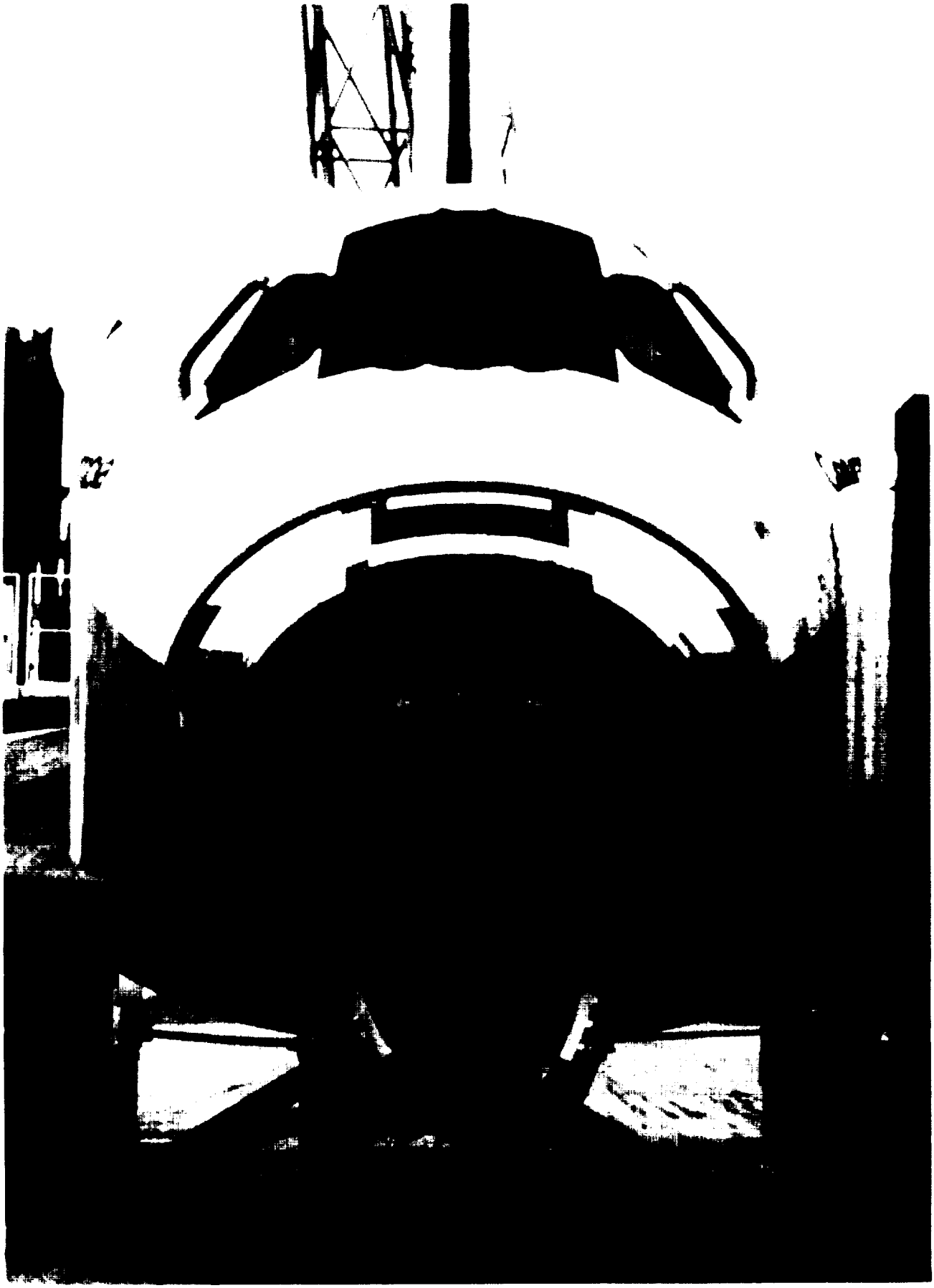


Photo 23: Overall View of Orbiter Nose

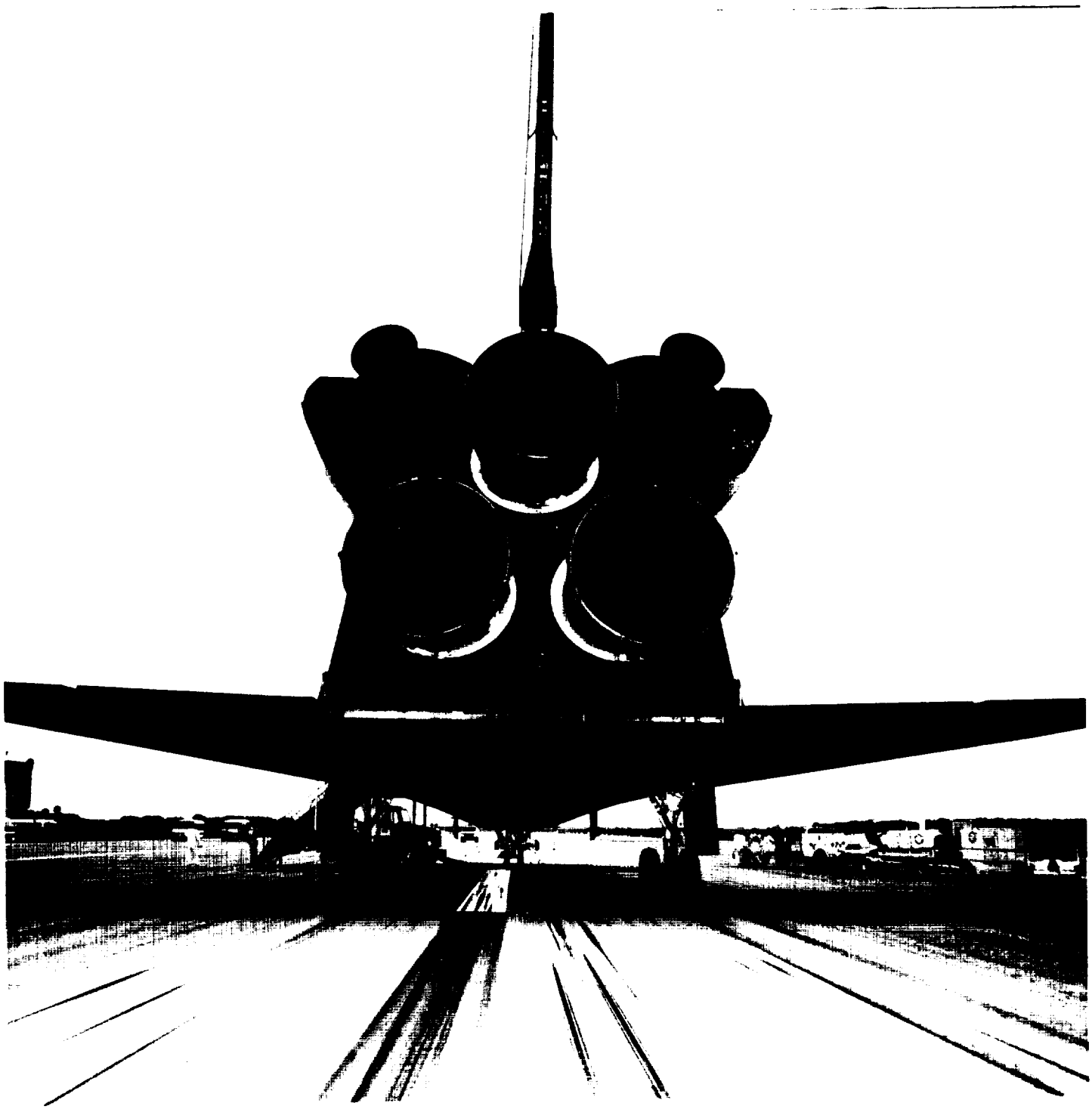


Photo 24: Overall View of Orbiter SSME's and Base Heat Shield

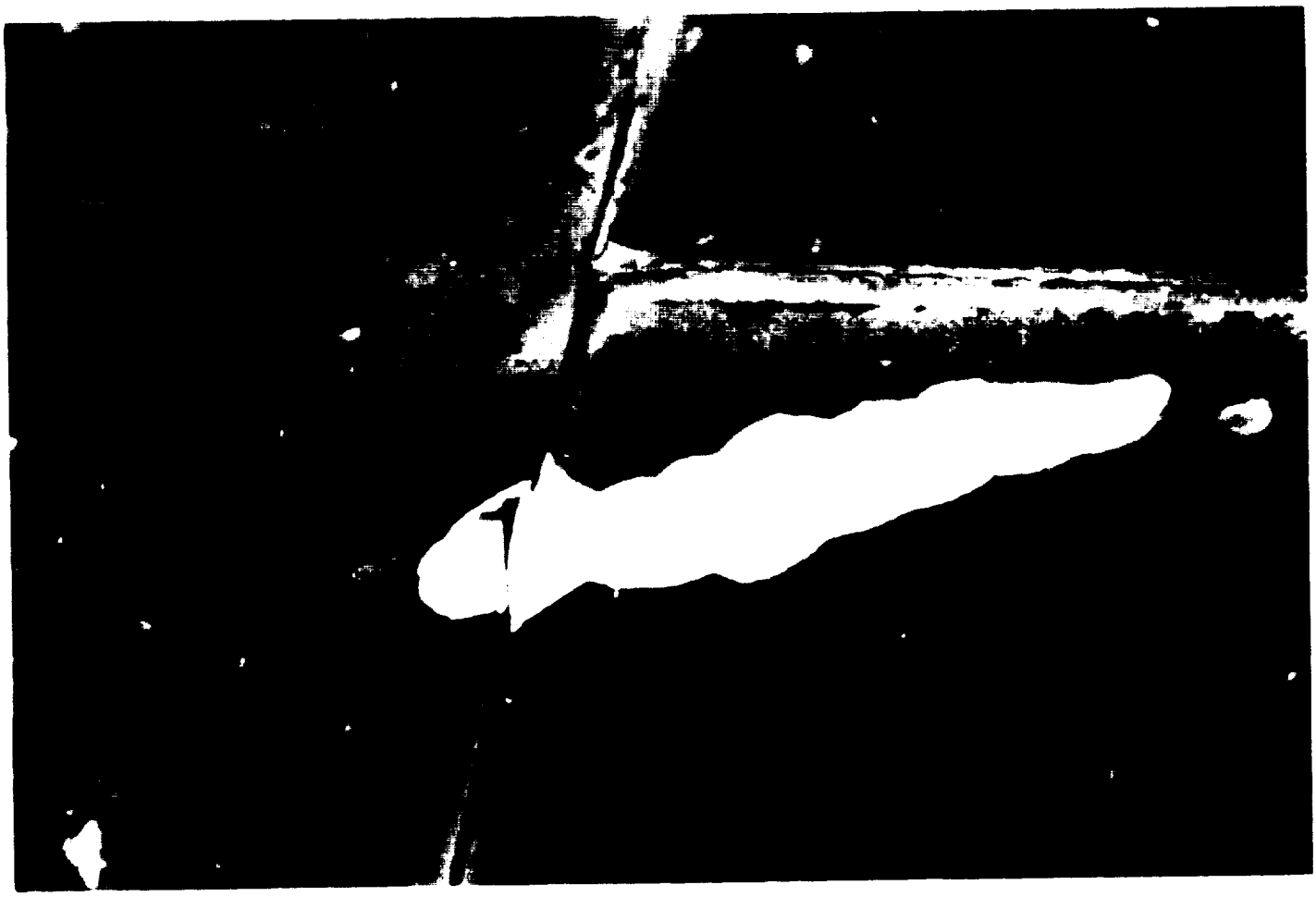


Photo 25: Lower Surface Tile Damage

The largest lower surface tile damage site was located aft of the LH2 ET/ORB umbilical and measured 3-inches long by 3/4-inch wide by 1/2-inch maximum depth The damage was most likely caused by an ice impact from the umbilical.

Photo 26: ET/ORB LH2 Umbilical

Photo 27: ET/ORB LO2 Umbilical

Photo 28: Bent Metal on LO2 ET Door

Bent metal, approximately 1-inch in length by 1/8-inch, was visible on the trailing edge of a shim between two bolt heads on the inside surface of the ET LO2 door. The shim was located at the +X+Y corner of the door.

Photo 29: LO2 ET Door Loose Debris

A small piece of wire, 3/8-inch long by 1/32-inch diameter, was wedged against a bolt head in the +X+Y corner of the door.

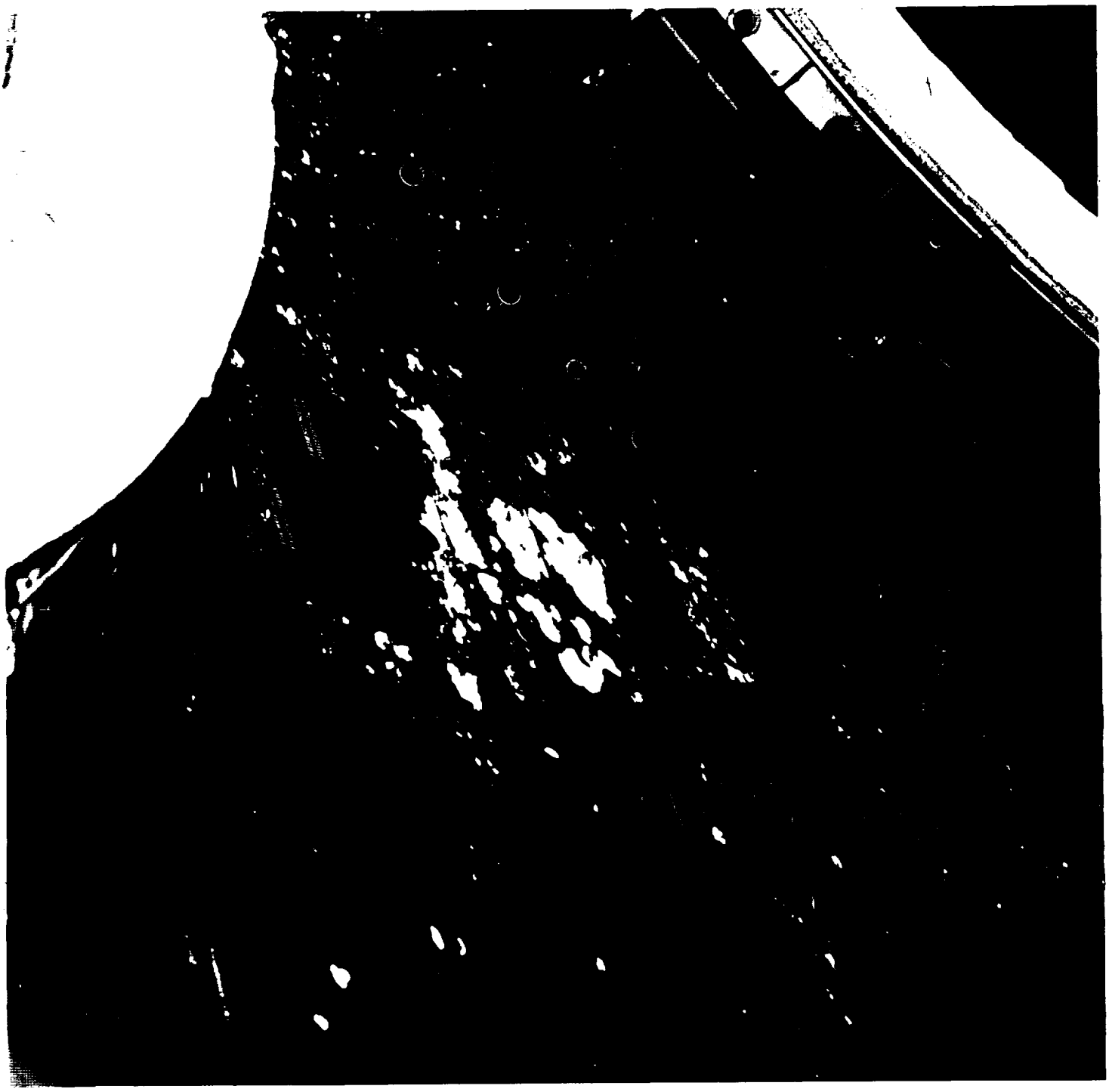


Photo 30: Base Heat Shield Tile Damage

A cluster of seven tiles on the base heat shield between SSME #1 and #3 sustained greater than normal damage, which may have been the result of debris impacts rather than plume recirculation effects. The tiles were missing a large percentage of surface area with the average depth measuring ¼-inch. This damage was observed during liftoff in the postlaunch film review.

Photo 31: Orbiter Windows 1-3

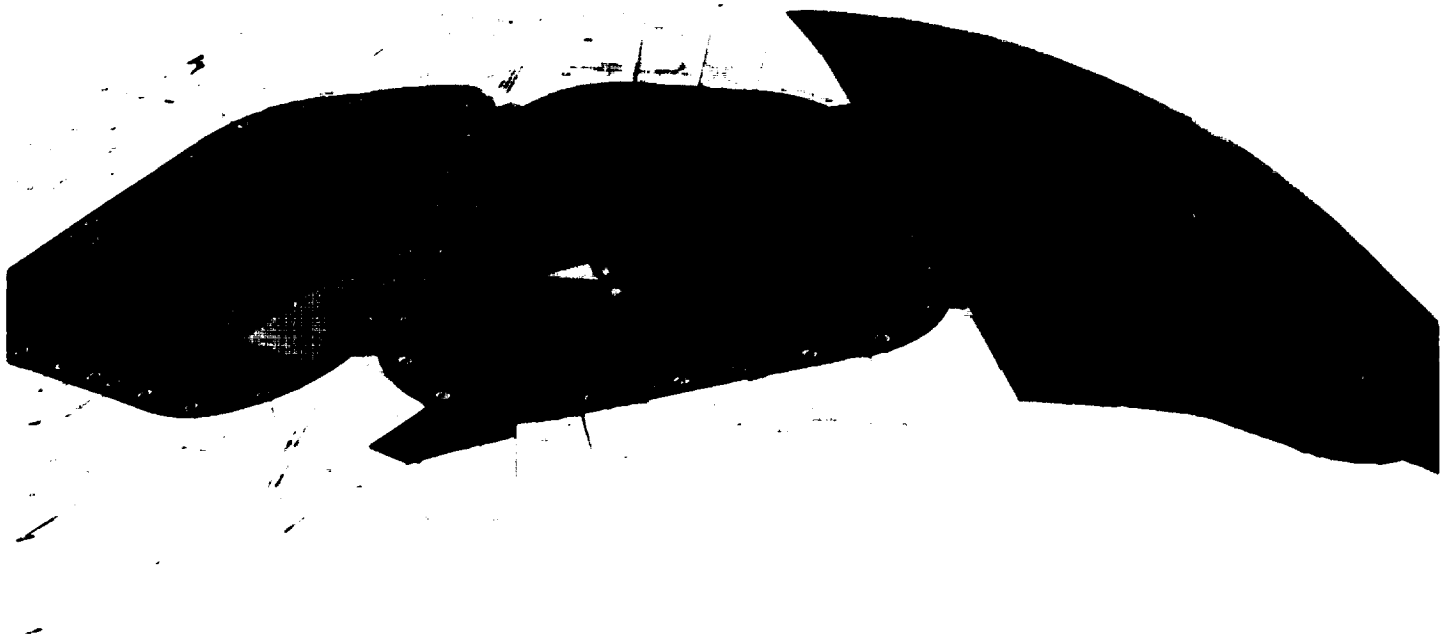


Photo 32: Orbiter Windows 4-6

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

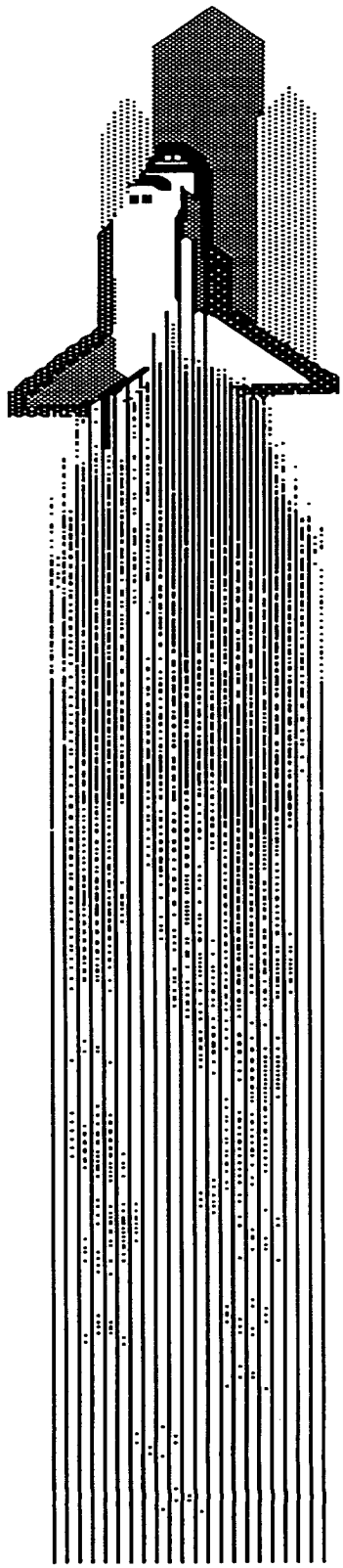
Space Shuttle

Earth Science Branch

Image Science and Analysis Group

STS-80 Summary of Significant Events

January 7, 1997



Space Shuttle Image Science and Analysis Group

STS-80 Summary of Significant Events

Project Work Order - SN-5LA

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Space and Life Sciences Directorate

Table of Contents

List of Figures and Tables

1. STS-80 (OV-102): FILM / VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-80 launch of Columbia (OV-102) from pad B occurred on Tuesday, November 19, 1996, (day 324) 19:55:47.160 Coordinated Universal Time (UTC) as seen on camera OTV150. Solid Rocket Booster (SRB) separation occurred at 19:57:50.994 UTC as seen on camera KTV13.

On launch day, 23 of 24 expected videos were received and screened. OTV148 was not received. Following launch day, 21 films were screened. Additional films were received but were not screened due to FY97 budget constraints. A bolt hang-up was seen at the LSRB holddown post M-7 at liftoff.

Detailed Test Objective 312, was performed using the Orbiter umbilical well cameras (method 1) and handheld photography (method 3). Photography of the LSRB separation and the external tank (ET) separation was acquired. Handheld photography of the ET was acquired using the Nikon F4 camera with the 300 mm lens and 2x converter (method 3).

1.1.2 On-Orbit

Video analysis support was provided to the investigation of the STS-80 airlock hatch anomaly. See section 2.5.1.

1.1.3 Landing

Columbia landed on runway 33 at the KSC Shuttle Landing Facility on December 7, 1996. Eleven videos were received and screened. Following landing, nine films were screened.

No major anomalies were noted in the approach, landing, or roll-out video and film views screened. The drag chute deployment appeared normal.

1.1.4 Post Landing

After landing, imagery of the ET/Orbiter LH2 umbilical acquired during SSME ignition through liftoff were reviewed for indications of hydrogen leaks. This imagery review was conducted at the request of the JSC Propulsion and Power Division / EP to support the Shuttle Program investigation of the higher than normal hydrogen values measured at the aft end of the vehicle just prior to liftoff. The Orbiter umbilical well camera films of the external tank LH2 umbilical were also studied for indications of hydrogen leaks in support of this investigation. No visual indications of hydrogen leaking were found.

1.2 TIMING ACTIVITIES

The time codes from videos and films were used to identify specific events during the initial screening process.

The landing and drag chute event times are provided in Table 1.2.

Event Description	Time (UTC)	Camera
Landing Gear - Doors Opened	342:11:48:42.068	KTV6L
Left Main Wheel Touchdown	342:11:49:03.823	KTV6L
Right Main Wheel Touchdown	342:11:49:04.056	KTV6L
Drag Chute Initiation	342:11:49:07.960	KTV6L
Pilot Chute at Full Inflation	342:11:49:08.839	KTV33L
Bag Release	342:11:49:09.507	KTV33L
Drag Chute Inflation in Reefed Configuration	342:11:49:10.508	KTV33L
Drag Chute Inflation in Dis-reefed Configuration	342:11:49:13.911	KTV33L
Nose Wheel Touchdown	342:11:49:16.514	KTV6L
Drag Chute Release	342:11:49:40.071	KTV33L
Wheel Stop	342:11:50:05.953	KTV15L

Table 1.2 Landing Video Timing Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition, at the time of SRB ignition, and aft of the launch vehicle after liftoff. Most of the debris were umbilical ice and RCS paper. No damage to the vehicle was noted. No follow-up action was requested.

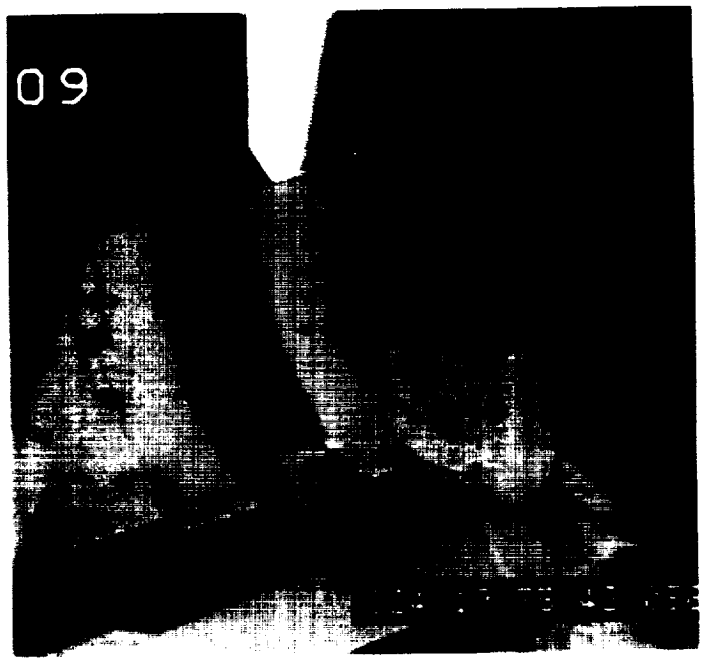

Figure 2.1 (A) Debris Striking LH2 Umbilical Electric Cable Tray

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals during SSME ignition. Ice debris was seen to strike the LH2 electric cable tray (19:55:43.056 UTC) and the LH2 umbilical well door sill (19:55:43.390, 19:55:44.324, and 19:55:45.158 UTC). Ice debris was seen to strike the LO2 umbilical electric cable tray during SSME ignition (19:55:42.489, 19:55:43.857, and 19:55:44.458 UTC). None of the debris seen to contact the vehicle appeared to cause damage. (Cameras OTV109, OTV154)

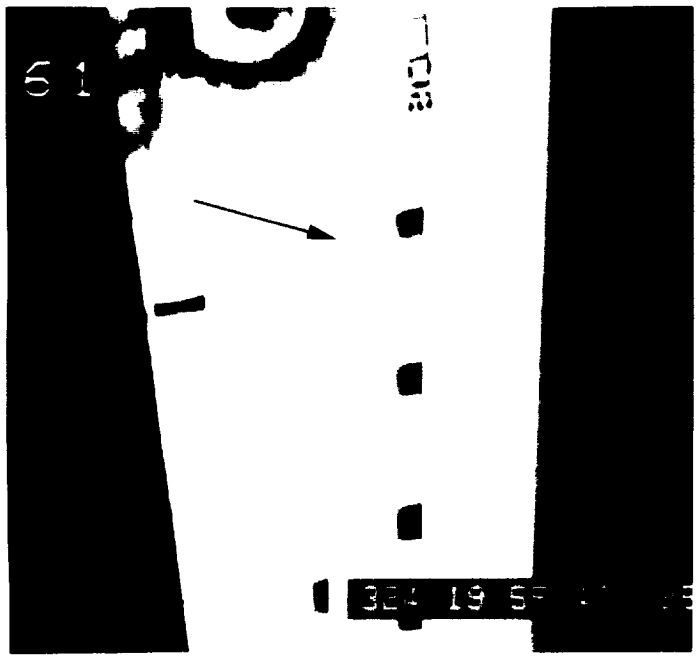

Figure 2.1 (B) Dark Debris At Liftoff

Several pieces of dark appearing debris were seen at SSME ignition. A dark piece of debris was seen falling aft along the vehicle during liftoff. A single piece of debris was seen crossing the left wing leading edge during liftoff. All of these objects were probably birds. None of the objects were seen to contact the vehicle. (Cameras OTV161, OTV163)

Figure 2.1 (C) Red Colored Debris Near Body Flap

A single, small, rectangular, red colored piece of debris was seen falling along the body flap just prior to SRB ignition (19:55:46.666 UTC). This debris may have been a tile shim or gap filler. (Camera E18)

Multiple pieces of debris from the SRB flame trench area (possibly SRB throat plug material) were seen north of the launch vehicle at liftoff. Debris north of the launch vehicle at liftoff has been seen on previous missions. At the same time, a piece of debris was seen falling along the north side of the FSS (19:55:47.8 UTC). These debris pieces were not seen to contact the vehicle. (Camera E52)

Multiple pieces of debris (probably umbilical ice and RCS paper) fell aft of the launch vehicle from liftoff through the roll maneuver. A single piece of light colored debris was seen between the SRBs during ascent (19:56:04.255 UTC). (Cameras E52, E54, E63, E212, E223)

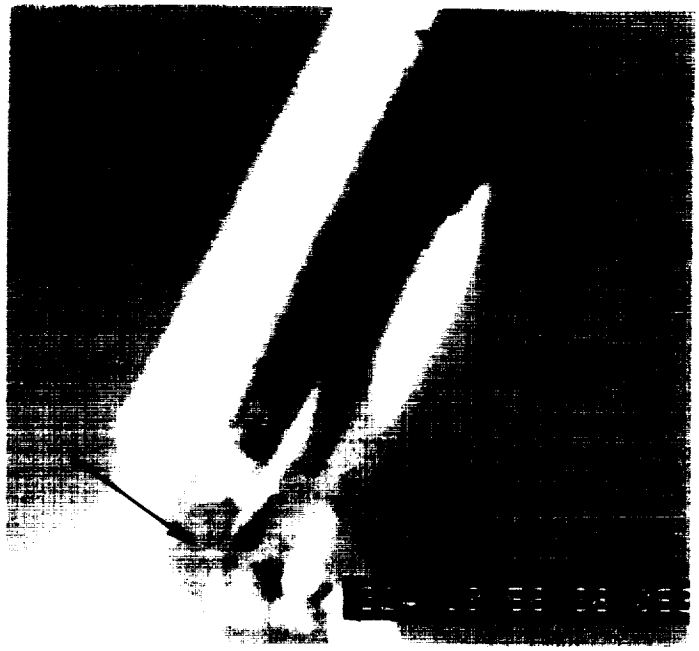

Figure 2.1 (E) Debris Near Body Flap During Ascent

A single light colored piece of debris (probably umbilical purge barrier material) was seen near the body flap during ascent (19:56:36.052 UTC). This debris did not appear to contact the launch vehicle. (Cameras KTV13, ET208)

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

The SSME Mach diamond formation occurred in the expected sequence. The times of the Mach diamond formation were (Camera E76):

SSME #3 -19:55:43.727UTC
SSME #2 -19:55:43.757UTC
SSME #1 -19:55:43.867UTC

Figure 2.2 (A) Orange Vapor Seen During SSME Ignition

Orange vapor, probably free burning hydrogen, was seen above the SSME rims, near the body flap, and near the base of the vertical stabilizer during SSME ignition (19:55:41.3 UTC). Orange vapors have been seen on previous missions. (Cameras OTV163, OTV171, E2, E4, E5, E17, E19, E20, E63, E76)

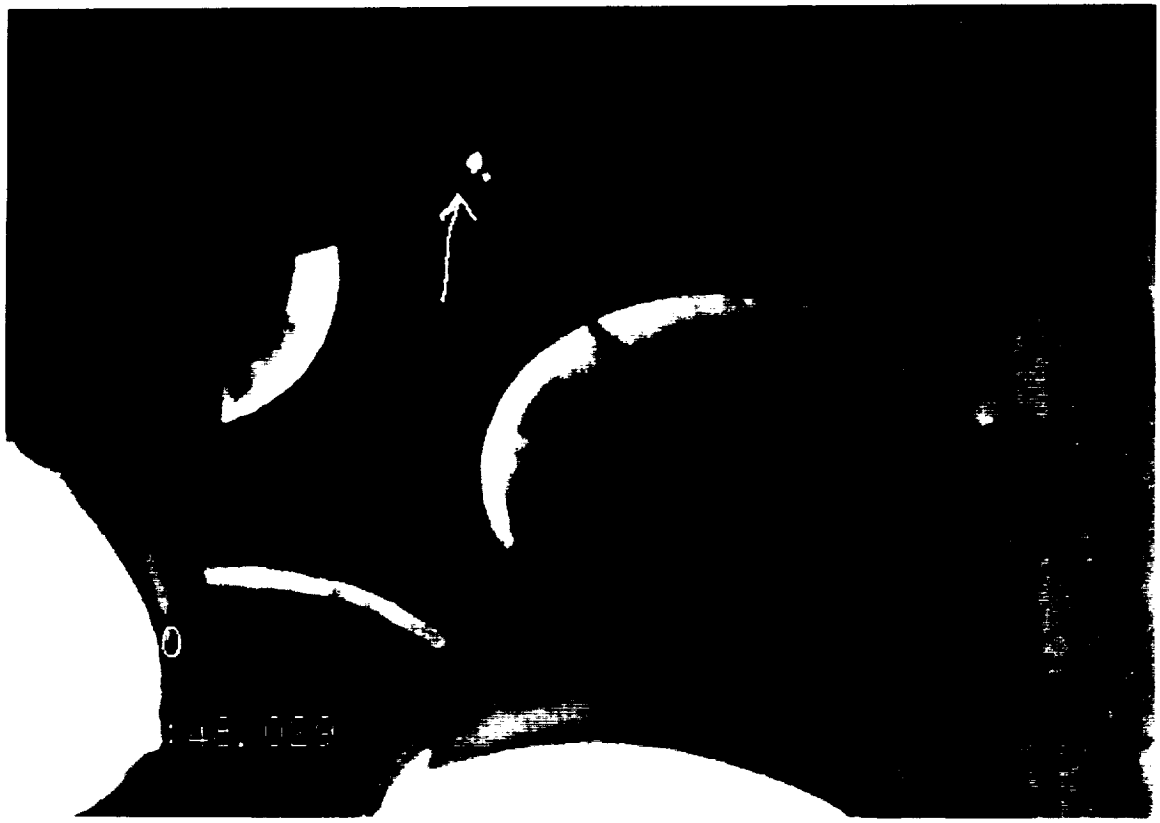

Figure 2.2 (B) White Areas On Base Heat Shield

A white line (probably frost) was seen at the base of SSME #2 at the juncture of the engine mounted heat shield-to-nozzle interface at liftoff. Accumulations of ice/frost on the heat shield-to-nozzle interfaces have been seen on previous missions. A small white area was also seen on the base heat shield near the inboard side of the right RCS stinger (missing tile surface coating material). (Cameras E18, E19, E20)

Three small areas of base heat shield TPS tile surface erosion were seen near the base of SSME #3 during SSME ignition. Two additional areas of base heat shield erosion were seen near the left OMS nozzle at approximately the same time. On camera E20, TPS erosion on the base heat shield was visible outboard of SSME #2. Erosion of base heat shield tile surface material has been typically seen on previous missions. (Cameras E17, E20)

Figure 2.2 (C) Bolt Hang-Up At Holddown Post M-7

A bolt hang-up was seen at the LSRB holddown post M-7 at liftoff (09:54:59.594 UTC). Debris fragments were seen near the DCS during the hang-up and bolt release. SRB holddown bolt hang-ups have been seen on six of the last eight previous missions. See Table 2.2. No follow-up action was requested. (Camera E11)

MISSION	LOCATION OF HANG-UP
STS-34	RSRB holddown post M-2
STS-33	RSRB holddown post M-3
STS-39	RSRB holddown post M-1
STS-43	LSRB holddown post M-7
STS-45	RSRB holddown post M-4
STS-50	RSRB holddown post M-4
STS-46	LSRB holddown post M-7
STS-53	RSRB holddown post M-1
STS-73	RSRB holddown post M-2
STS-75	LSRB holddown post M-5
STS-76	LSRB holddown post M-5
STS-78	LSRB holddown post M-5
STS-79	RSRB holddown post M-3
STS-80	LSRB holddown post M-7

Table 2.2 SRB Holddown Post Bolt Hang-Ups Seen On Previous Missions

2.3 ASCENT EVENTS

An orange colored flare was seen in the SSME exhaust plume prior to the roll maneuver at 19:55:55.817 UTC (camera E52). On camera E212, three flares were seen in the SSME exhaust plume at approximately 19:56:16, 19:56:31.9, and 19:56:32 UTC. On Cameras E212 and E222, a single piece of debris, first seen near the RSRB aft skirt, contacted the SSME exhaust plume resulting in an orange colored flare (19:56:28.7 UTC). Flares in the SSME exhaust plumes have been seen on previous missions. (Cameras E52, E212, E222)

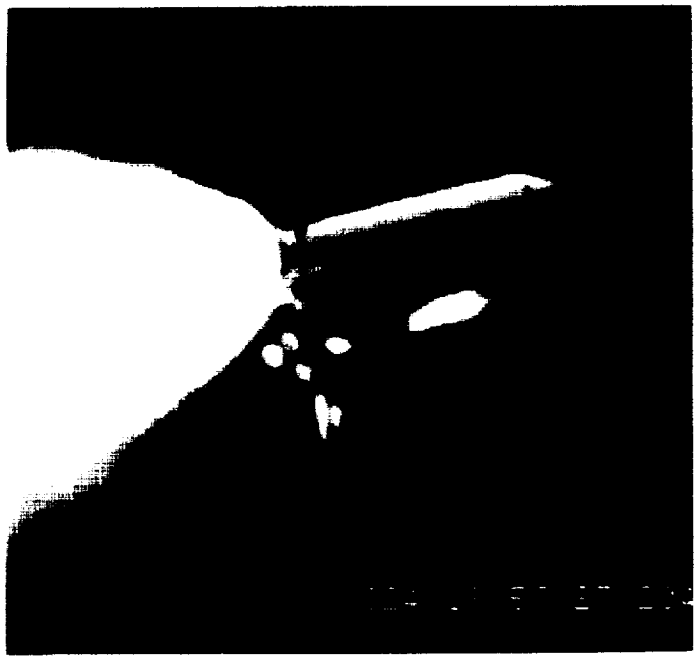

Figure 2.3 (A) Recirculation At Aft End Of Vehicle

Recirculation, or the expansion of burning gasses at the aft end of the vehicle, was seen during ascent (19:57:20 - 19:57:37 UTC). Recirculation during this time period has been seen on previous missions. (Cameras KTV13, ET204)

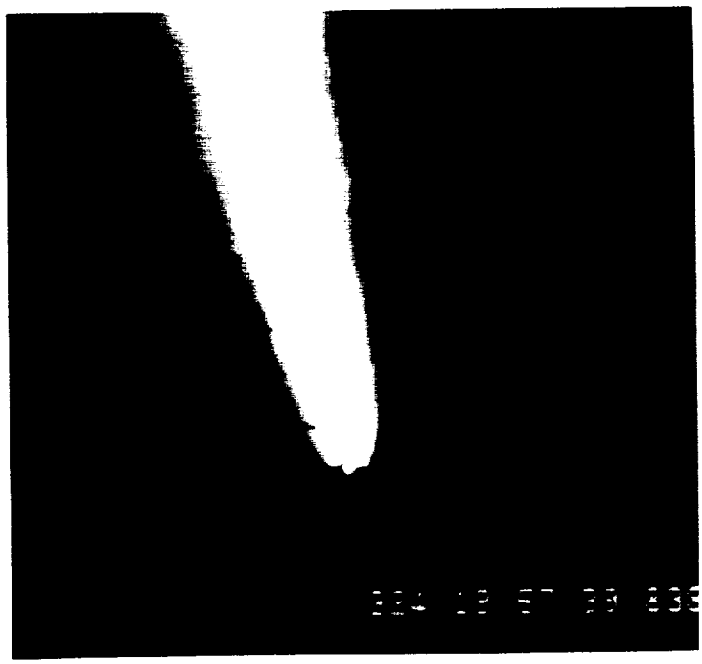

Figure 2.3 (B) Dark Puff In SRB Exhaust Plume

A dark puff was seen in the SRB exhaust plume at 11.1 seconds prior to SRB separation (19:57:39.8 UTC). (Cameras KTV4B, ET204)

2.4 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (DTO-312)

2.4.1 Analysis of the Umbilical Well Camera Films (Task #2)

Three rolls of STS-80 umbilical well camera film were acquired: the 16mm film (5mm lens), the 16mm film (10mm lens) from the LH2 umbilical, and the 35mm film from the LO2 umbilical.

Sixty-five images of the external tank were acquired with the 35mm umbilical well camera. The nose of the ET was not imaged on the 35mm umbilical film because the +X translation was not performed.

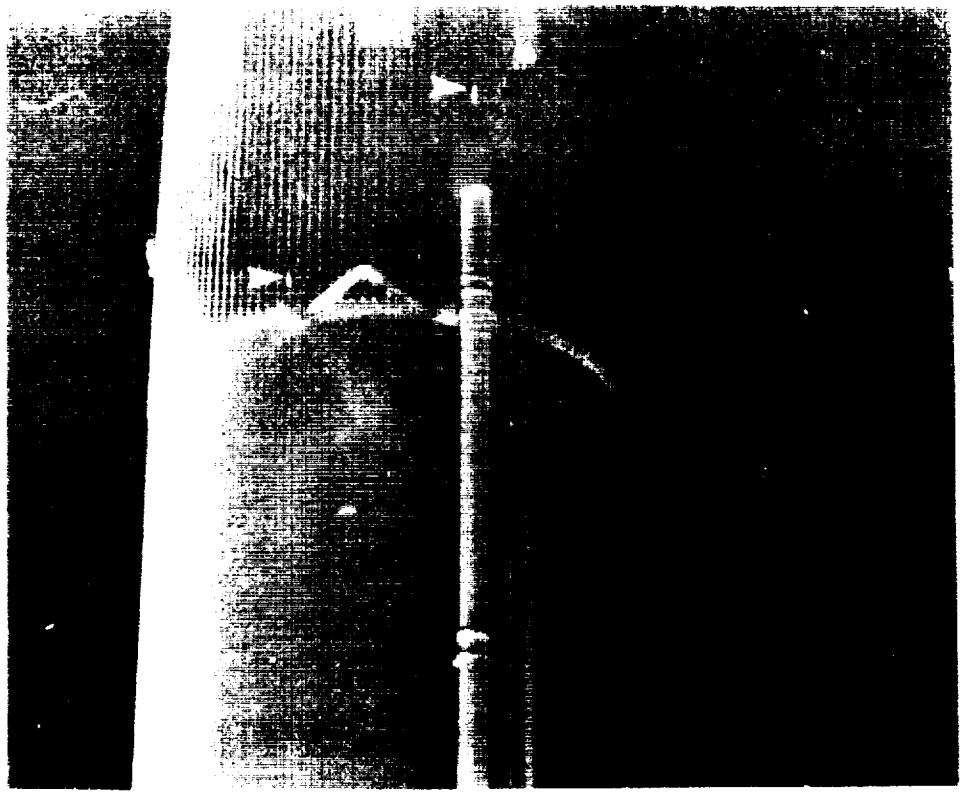

Figure 2.4.1 (A) ET Intertank

Three divots on the intertank stringers on the +Z side of the ET were seen (two divots were forward of the bipod and one was forward of the LO2 feedline).

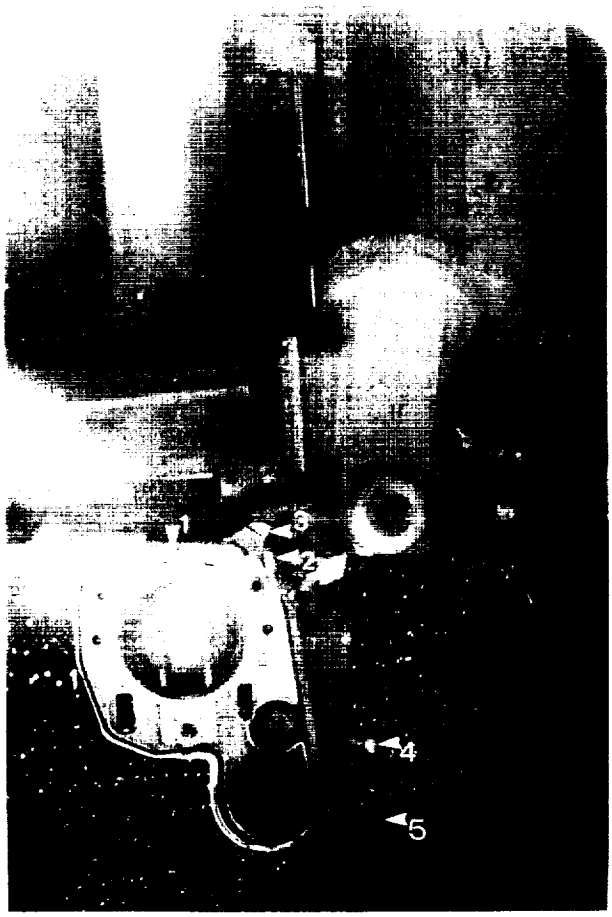

Figure 2.4.1 (B) LO2 Umbilical

Two of the five lightning contact strips (12 and 8 o'clock positions) on the ET/Orbiter LO2 umbilical interface plate were seen to be missing (1). Missing lightning contact strips have been previously seen (as recently as STS-78) and are the subject of an in-flight anomaly (IFA). A separate object (possibly RTV purge barrier material) appeared to be partially detached at the 2 o'clock position of the LO2 umbilical (2). A detached piece of insulation material (TPS) was seen at the forward right corner of the LO2 umbilical (3). TPS surface erosion/divots were noted on vertical section of the LO2 electric cable tray(4). Typical erosion or chipping of the TPS on an aft LO2 feedline flange was noted. A small light-colored string-shaped piece of debris was visible near the ET aft dome on frame 21.

The new TPS agent 24-57 was used on the STS-80 (ET 80) hydrogen (H2) tank aft dome. Multiple faint, light-colored marks are visible on the charred H2 tank aft dome TPS (5). Blistering of the LH2 ET/Orbiter umbilical fire barrier coating was typical.

A piece of debris (dark on one side and light colored on the other side) was seen near the LH2 electric cable tray. A large appearing, dark colored, somewhat

rectangular shaped piece of debris was seen coming from behind the electric cable tray (5mm lens, frame 676). An irregular shaped piece of debris was seen during SRB separation (5mm lens, frame 1170).

Numerous light colored pieces of debris (probably insulation and frozen hydrogen) were seen though out the ET separation sequence on the 16mm films. Vapor and multiple light colored pieces of debris were seen after the umbilical separation. White debris (frozen hydrogen) were seen striking the forward surface of the LH2 electric cable tray (5mm lens, frames 3239 and 4856). No damage to the cable tray was detected. A large appearing piece of debris (white-colored on one side and dark colored on the other side) was seen traveling in the -Y direction in front of the LH2 umbilical after ET separation.

No anomalies were noted on the face of the LH2 umbilical after ET separation (the LH2 umbilical interface plate appeared similar to previous mission views). As typically seen on previous missions, frozen hydrogen was noted on the orifice of the LH2 17 inch connect. Normal burn scars were seen on the ET near the forward SRB attach points and the forward bipod.

Good coverage of the LSRB separation was acquired. As on previous missions, numerous light-colored pieces of debris (probably insulation) and dark debris (probably charred insulation) were seen throughout the SRB film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of horizontal section of the -Y ET/SRB vertical strut were seen.

2.4.2 Analysis of Handheld Photography of the ET (Task #3)

One roll of handheld photography was taken using the Nikon F4 with the 300 mm lens plus 2X extender. An early OMS-2 pitch maneuver was performed to bring the external tank into view. Nine frames were acquired during a two minute and twenty-nine second time period.

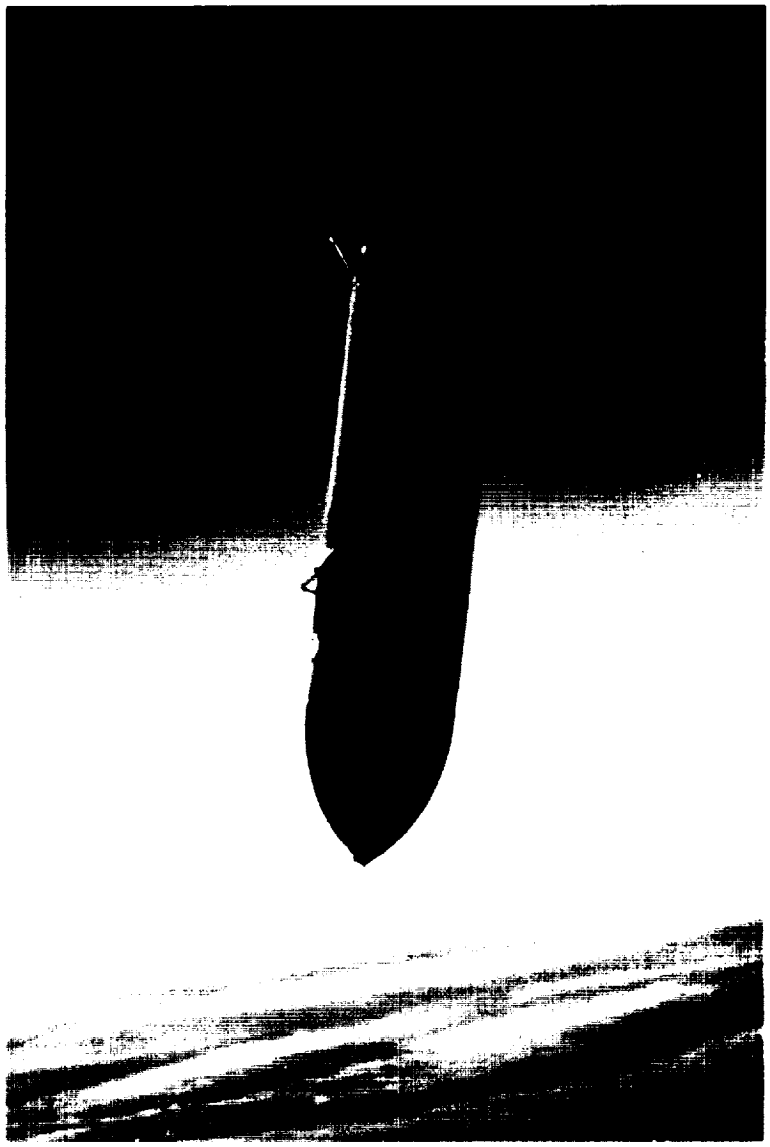

Figure 2.4.2 (A) Handheld View Of The External Tank

As can be seen above, back-lighting from the sun degraded the handheld views of the external tank. The previously used foam-covered intertank access door was flown on STS-80 (ET 80). The condition of the intertank access door could not be determined due to the poor lighting conditions.

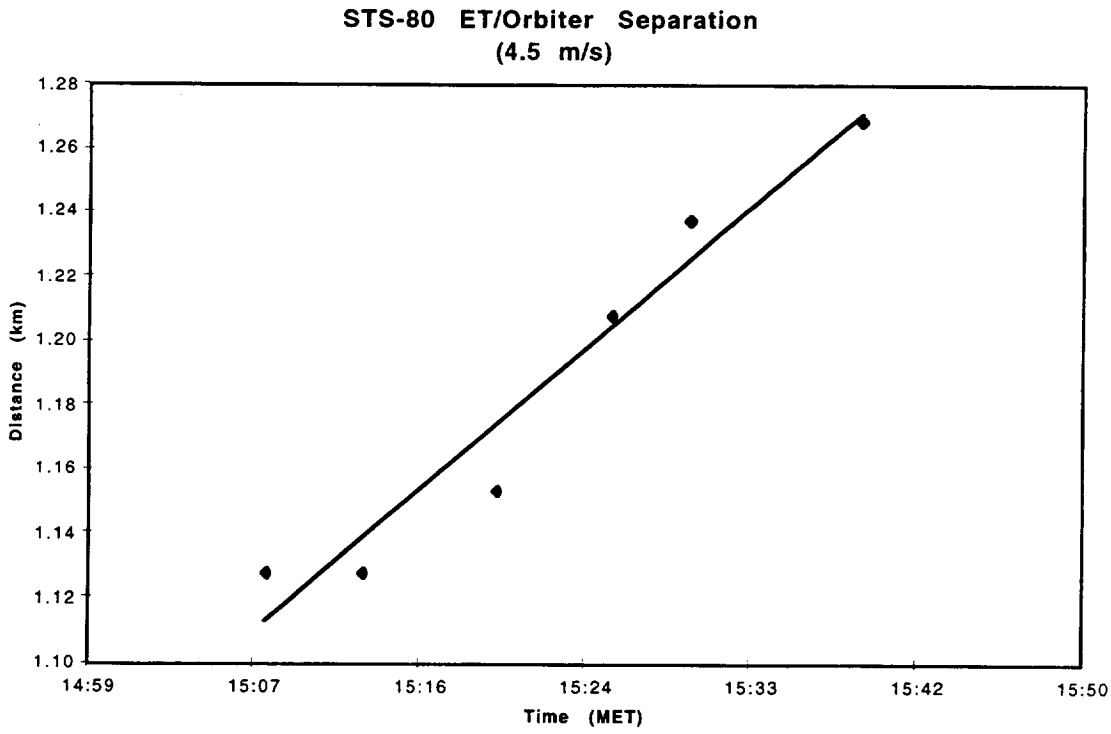

Figure 2.4.2 (B) ET Separation Velocity

The distance of the external tank was calculated over a six-frame sequence using the handheld photography. The external tank was calculated to be a distance of 1.1 km away from the Orbiter at 15:08 MET. The tank was calculated 31 seconds later (15:39 MET) to be at a distance of 1.3 km. The tank separation velocity was determined to be 4.6 m/s. The separation velocity was similar to previous mission measurements. The tank tumble and roll rates could not be determined due to the poor lighting conditions.

2.5 ON ORBIT EVENTS

2.5.1 Video Analysis of STS-80 Airlock Mechanism

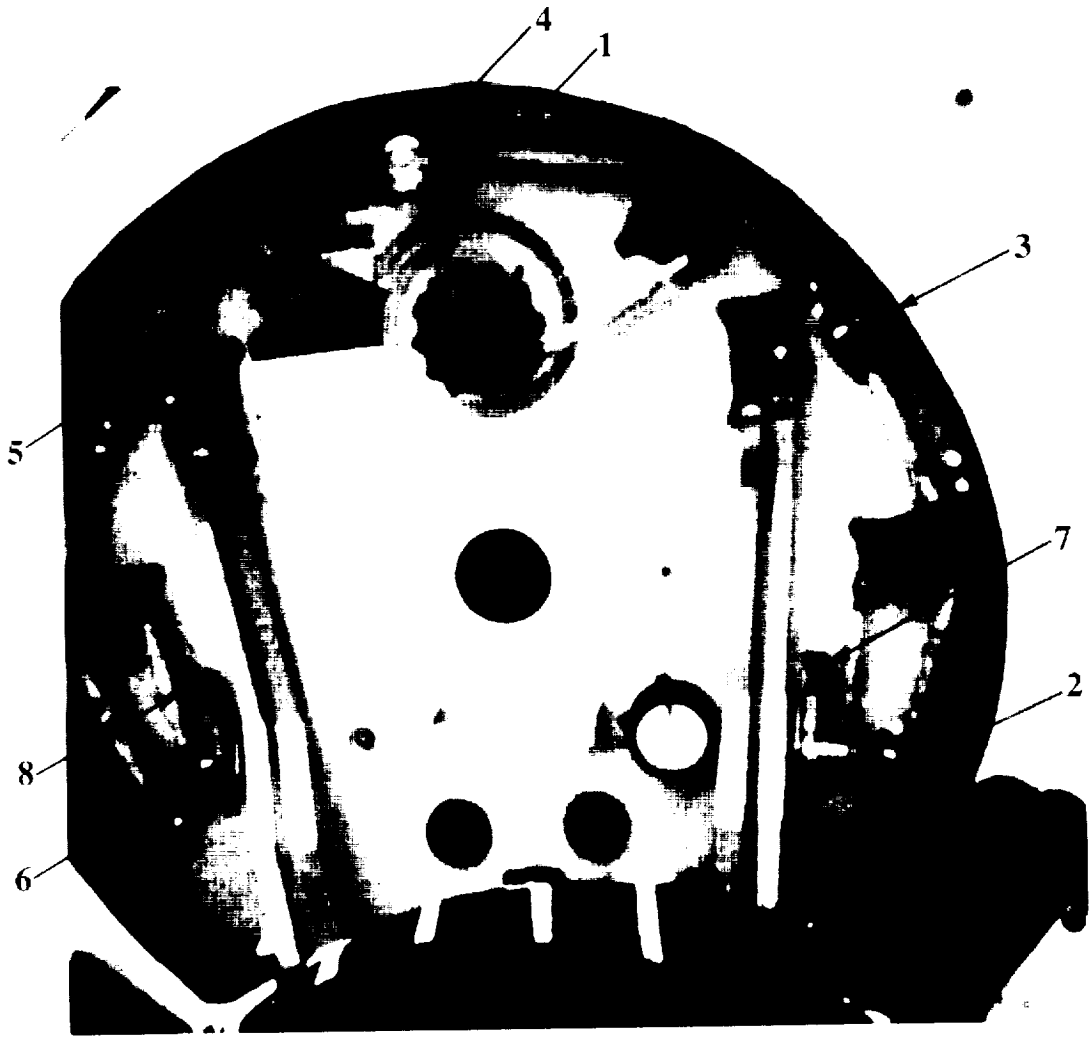

Figure 2.5.1 Airlock Hatch (Exterior)

Annotation 1 Handle attached to gear box mechanism
Annotation 2 Latch #2
Annotation 3 Latch #3
Annotation 4 Latch #4
Annotation 5 Latch #5
Annotation 6 Latch #6
Annotation 7 Starboard deployable leg
Annotation 8 Port deployable leg

To assist in the investigation of the STS-80 airlock hatch anomaly, the SN5 Image Science and Analysis Group provided information on four requested tasks to the Space Shuttle Program based on the analysis of down-linked video:

Request (1) Determine the orientation of the six hatch latches for the fully latched position of the actuator handle relative to the "jammed" position.

The orientation of each latch link was measured relative to the deflection angle of each latch link using close-up views from video acquired with the end-effector camera positioned approximately face-on to each latch link (Figure 2.5.1, annotations 2-6). The total rotation of a latch link from fully latched to its dead-on-center (DOC) perpendicular orientation was approximately 2.15 degrees. At the maximum jammed position, latches 1, 2, 3, and 4 were definitively observed to rotate beyond DOC in the unlatched direction (total rotations from fully latched of 5.5, 4.9, 5.8 and 7.5 degrees respectively). Latches 5 and 6 were observed to probably rotate beyond DOC in the unlatched direction, but the observations were not definitive due to uncertainty in the measurements.

Request (2) Determine the relative times that the six latches reached their jammed positions.

Video of the hatch that provided coverage of all six latches simultaneously during deflection of the actuator handle was not available. Therefore request 2 was not accomplished.

Request (3) Determine the relative times that the two deployable legs reached their jammed positions.

Video of the simultaneous motion of both deployable legs was analyzed (Figure 2.5.1, annotations 7 and 8). Both legs reached their jammed position within one video frame of each other, corresponding to a time difference of less than approximately 0.03 seconds. The starboard leg reached its jammed position first.

Request (4) An inspection of the starboard deployable leg mechanism for evidence of debris.

Close-up views of the starboard deployable leg mechanism were inspected for evidence of debris, in support of the "smart bolt" theory as the cause of the jamming. Six separate video segments were inspected. No evidence of debris was seen.

During the post-flight inspection conducted by engineers at KSC, a loose screw was found lodged in the actuator gearbox (Figure 2.5.1, annotation #1). This loose screw jammed the handle preventing the crew from opening the hatch on orbit.

2.5.2 Orbiter Window Pitting

A D2 copy of the video tape of the pitting seen on the Orbiter left hand overhead window (#8) was requested from the Imagery and Publications Office / BT4. The video of the pitting was screened, however, the Moir reported that no imagery analysis was required.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis (Task #1)

Video camera SLF-South was used to determine the landing sink rate of the main gear (film cameras did not provide adequate views of the main gear sink rate). Landing film E7 was used to determine the nose gear sink rate. The sink rates of the Orbiter were determined over a one-second time period prior to main and nose gear touchdown.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle (the landing weight of the STS-80 Orbiter was reported to be 227,523 lb.). The sink rate measurements for STS-80 are given in Table 2.6.1. In Figure 2.6.1(A), and 2.6.1(B), the trend of the measured data points for the image data is illustrated.

Prior to Touchdown (1 Second)	Sink Rate: Film
Main Gear	1.5 ft/sec
Nose Gear	4.0 ft/sec

Table 2.6.1 Sink Rate Measurements

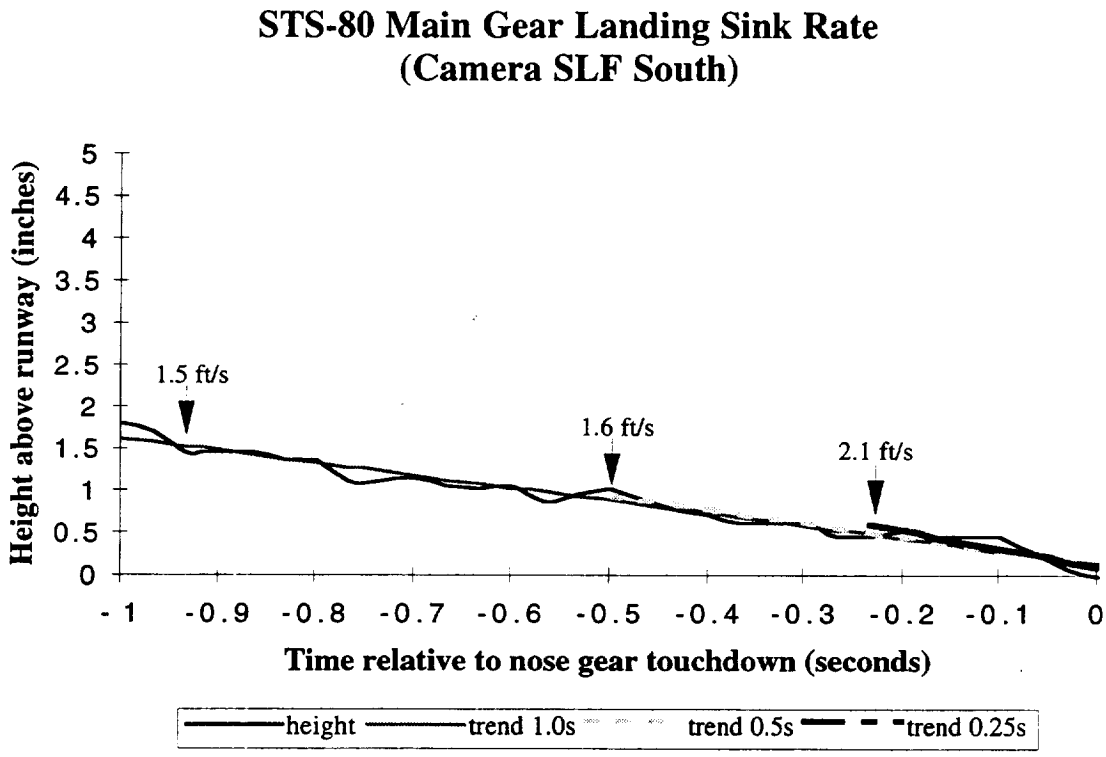

Figure 2.6.1 (A) Main Gear Height Versus Time Prior To Touchdown (Video)

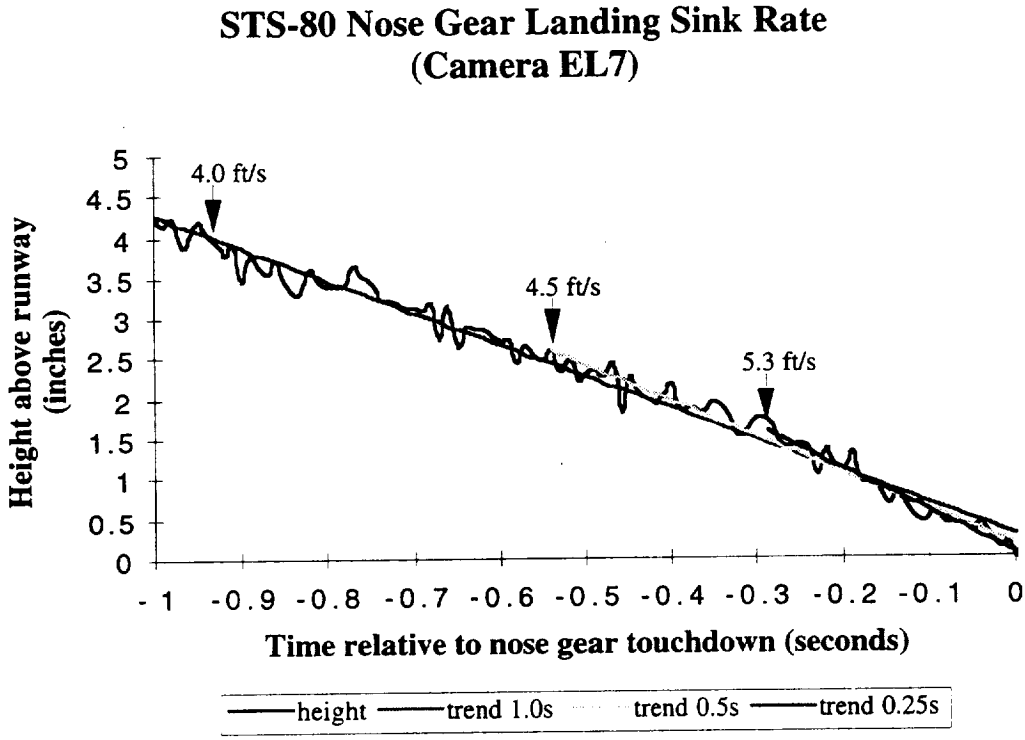

Figure 2.6.1 (B) Nose Gear Height Versus Time Prior To Touchdown (Film)

2.7 OTHER

2.7.1 Normal Events:

Other normal events observed include: ice and vapor from the ET/Orbiter umbilical areas from SSME ignition through liftoff, inboard and outboard elevon motion at SSME ignition, RCS paper debris during SSME ignition through liftoff, ET twang, multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals prior to and at disconnect, ET aft dome outgassing and vapor off the SRB stiffener rings during liftoff, vapor and ice from the GUCP area during ET GH2 vent arm retraction, slight left OMS nozzle vibration at SRB ignition, debris in the exhaust cloud after liftoff, expansion waves after liftoff, roll maneuver, slight body flap motion, linear optical effects, condensation around the launch vehicle after the roll maneuver, ET aft dome charring, recirculation, SRB plume brightening prior to SRB separation, SRB separation, and SRB slag material in the SRB exhaust plume before, during, and after SRB separation.

2.7.2 Normal Pad Events Observed Were:

Hydrogen burn ignitor operation, FSS deluge water operation, GH2 vent arm retraction, LH2 and LO2 TSM door closure, MLP deluge water operation, and sound suppression system water operation.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of: EP42 (97-02)

January 5, 1997

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-80

The launch of space shuttle mission STS-80, the twenty-first flight of the Orbiter Columbia occurred on November 19, 1996, at approximately 1:55 P.M. Central Standard Time from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Photographic and video coverage was evaluated to determine proper operation of the MSFC related flight hardware.

Film was received from forty-three cameras as well as video from twenty-four requested cameras. The afternoon launch provided good lighting conditions for the engineering photography of STS-80 launch. Clouds partially obscured the views from several tracking cameras. Tracking cameras E204 and E222 were out of focus. The film from perimeter camera E60 was fogged and not shipped to MSFC. Short-range tracking camera E59 experienced a short run. Water droplets on several MLP camera exposure lens ports reduced the image resolution prior to and during liftoff.

Approximately one minute of ET video after separation was recorded by the astronauts and downlinked. This imagery is backlighted by the sun and provided little detail on the ET TPS condition. Nine images of the ET were recorded by the astronauts using a 35mm camera. These images were also strongly backlighted by the sun. The 16mm motion picture cameras and 35mm still camera in the orbiter's umbilical wells provided good coverage of the SRB and ET separation events as well as the ET TPS condition.

Holddown post M-7 experienced a stud hang-up. This event is similar to previous hangs where the stud remains fully extended until the vehicle clears the stud. The stud then falls back into the catch mechanism. No explosive bolt debris was noted coming from the containment system.

A greater than usual amount of ice/frost was noted around the GUCP. No damage to the TPS was noted.

Frost was noted around the SSME #2 eyelid prior to liftoff. This frost has been noted on previous missions.

Orange flames were observed on the outside of ME-2 nozzle (-Z) during engine start near the #9 hatband. These flames were visible for approximately one second starting at 19:55:44.5 UTC.

A piece of debris was seen to fall from the right ET/SRB lower attach strut (EB-8) at 57:19:56:00.678 UTC. Other white glowing debris which is typical of what has been seen on other missions was observed originating from the RSRB plume.

Flow recirculation was evident on this mission as recorded by the long-range tracking cameras. This event is typical of every shuttle launch and was visually enhanced by the clear sky conditions. The amount of recirculation appears to be typical of previous missions.

A small portion of TPS was missing on the vertical strut at the aft orbiter/ET (EO-2) attachment as recorded by the on-board LH2 umbilical well camera. This missing TPS was first observed when the camera began operation just prior to SRB separation.

An unusually large piece of TPS foam was observed traveling from right to left in the LH2 umbilical well camera's field-of-view after separation. The shape of the foam piece suggests that the source may be from the LO2 disconnect.

A small portion of TPS was noted missing on the diagonal strut near the LO2 disconnect in the LO2 umbilical well 35mm camera film. "Popcorning" of the LH2 tank aft dome TPS is also apparent.

Two divots were observed in the +Z region of the intertank on the LO2 umbilical well 35mm camera film. One divot is located forward of the LO2 feedline fairing and the other forward of the bipod strut. The divots' linear shapes are aligned along the stringers and the metal primer appears visible. Divots of this type have been observed before.

The following event times were acquired.

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	19:55:46.998	Camera E-9
M-2 PIC Firing	19:55:46.998	Camera E-8
M-5 PIC Firing	19:55:46.996	Camera E-12
M-6 PIC Firing	19:55:46.999	Camera E-13
SRB separation	19:57:51.01	Camera E-208

This report and additional information are available on the World Wide Web at URL:

http://photo4.msfc.nasa.gov/STS/sts80/sts80.html.

For further information concerning this report contact Tom Rieckhoff at 544-7677 or Jeff Hixson, Boeing North American at 971-3082.

Thomas J. Rieckhoff

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-80. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Shuttle mission STS-80 and the resulting effect on the Space Shuttle Program.

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